PRICE TEN SHILLINGS AND SIXPENCE.

THE JOURNAL OF

The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY P. F. ROWELL, SECRETARY

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2

Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

Vol. 76 MAY, 1935 No. 461

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E. and F. N. SPON LIMITED, 57 HAYMARKET, LONDON, S.W.
ENGINEERS BOOK SHOP, 227 PARK AVENUE, NEW YORK.

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[*Continued on page (III) of Cover.*

THE ELECTRICAL WARMING OF, AND THE SUPPLY OF HOT WATER AND CONDITIONED AIR TO, LARGE BUILDINGS.

By R. GRIERSON, Member, and D. BETTS, Associate Member.

[*Paper first received* 18*th December*, 1933, *in revised form* 17*th September*, 1934, *and in final form* 2*nd March*, 1935; *read before* THE INSTITUTION 6*th December*, *before the* IRISH CENTRE 15*th November*, *before the* NORTH-WESTERN CENTRE 20*th November*, *before the* SHEFFIELD SUB-CENTRE 21*st November*, *and before the* WESTERN CENTRE 17*th December*, 1934, *also before the* NORTH MIDLAND CENTRE 8*th January*, *before the* SOUTH MIDLAND CENTRE 14*th January*, *before the* DUNDEE SUB-CENTRE 21*st January*, *before the* SCOTTISH CENTRE 22*nd January*, *before the* NORTH-EASTERN CENTRE 11*th February*, *before the* EAST MIDLAND SUB-CENTRE 26*th February*, *and before the* MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 11*th March*, 1935.]

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INTRODUCTION.

Following the papers presented to this Institution by Messrs. S. E. Monkhouse and L. C. Grant,* R. Grierson,† and A. H. Barker,‡ and the publication of the British Electrical Development Association brochure,§ it is thought that it is now generally agreed that the commercial practicability of electric space-, air-, and water-heating, has been satisfactorily established for many types of buildings located in areas where the conditions of supply are suitable, and it is therefore the intention of

* See Bibliography, (1). † *Ibid.*, (2). ‡ *Ibid.*, (3). § *Ibid.*, (4).

the authors to deal in the present paper with the tactics rather than with the strategy of the subject. In other words, it has been assumed that the principles of electric heating have been accepted, given suitable conditions, and that it is the method of execution that now calls for examination and discussion, so that development may now proceed along well-ordered lines, calculated to bring credit to the industry that sponsors it.

As the problems of space- and water-heating and air-conditioning are so closely allied, the authors consider that the salient points of development can be conveniently discussed at the same time, and they have therefore extended the paper to cover the three applications.

So far from being a complete and definitive scientific treatise on the application of electrical energy to the heat problems associated with domestic buildings, the paper partakes more of the nature of leaves selected from the notebook of one who is perpetually engaged in endeavouring to answer the eternal questions "How?" and "Why?" It is offered with the intention of stimulating an interesting interchange of views with fellow engineers engaged in solving similar problems and also different aspects of the same problem. If that interchange of views materializes, the labour involved in the preparation of the paper will be more than amply repaid.

Part I. General Considerations Relating to the Utilization of Electrical Energy for Warming Purposes.

(1) Economic Rate.

Although suitable conditions of supply of electricity for the warming and ventilation of buildings and for hot-water supply on a large scale depend mainly, of course, on the nature of the supply authority's load graph, they are also related to the character of the building itself, and especially to the extent to which electricity is used in the building for other purposes. There are many instances in which a supply authority, while unable to quote a rate which is so low as to justify the use of electricity for heating, yet can submit a tender for the complete heating, lighting, cooking, and power, supply to the building, the acceptance of which will justify additional expenditure on the heating and hot-water services, by balancing the excess cost against the savings effected on the cost of electricity for the other services.

A basis for the discussion of this aspect of the problem is contained in the comment which is frequently made by those unfamiliar with the detailed study of the subject, namely that in order to justify electric heating as compared with the use of a coke-fired boiler and hot-water or steam radiators, electricity must be sold at 0·1d. per kWh. It is in the word "justify" that the fallacy lies.

Assuming for the moment that 0·1d. is the purchase price of 3 410 B.Th.U. in either form (it is really what the comment is intended to convey), the question to be answered is "How much more can the user be recommended to pay if this quantity of heat is supplied electrically, in a high-grade 'ready to use' form, instead of in the form of crude fuel or raw material which requires to be burned in a grate, bearing in mind the fact that this quantity of purified heat can be made to go very much further by the use of enlightened methods in the application of electricity?"

The effect of the practical elimination of labour, dust, and dirt, and similar amenity values, can be assessed in money and credited to the electrical method. In some cases a further credit may even be allowed for luxury value, for example in very high-grade flats and apartments, where the cost of the heating and hot-water services, in any case, forms a comparatively small percentage of the total receipts from rentals. Again, the ability to plan the building without the necessity of considering a boiler chimney or the direction of the prevailing wind in relation to the site, is of very considerable value to the architect.

Even in cases where such credits do not exist, or are insufficient to tip the scale in favour of electricity, the economy resulting from certain methods of application and control of electricity as a source of heat, and the precautions which can be taken in the design and in the construction of buildings against wasteful loss of heat (the capital cost of which may not be justified in a case where cheap fuel is being used) would in many cases so reduce the heat requirement of the building, in comparison with that of a fuel-heated installation, as to equalize the total running costs of the two methods.

(2) Conservation of Fuel.

Many critics of electrical warming propositions refer to the appalling destruction of fuel and quote figures for power station efficiency of from 18 to 25 per cent. If this argument is really sound, then it is submitted that the Coal Utilization Council should be included amongst the strongest supporters of the inefficient electric method of warming buildings, for they have announced in the Press the launching of a campaign in which scientific selling methods will be employed to induce the public to buy more British coal, and it has been stated that it is proposed to spend £60 000 on the campaign.

Again, it has been repeatedly stated that the overall thermal efficiency of the electric method of warming is lamentably low and that it must be cheaper to burn the coal or to manufacture the heat on the site rather than by mass-production methods at the power station, but this argument entirely disregards the fact that, in the London area, the householder has to pay anything from 37s. 6d. up to 75s. per ton for his household fuel, whereas the fuel clause in the contracts of the Central Electricity Board are based on prices of the order of 13s. to 18s. per ton, figures which show a very substantial balance in favour of the electrical method at the very outset. It is suggested that critics of the electrical method might profitably study the possibility of burning the cheap power-station coal in their dining-room grates and in their kitchen ranges.

Another aspect of the matter is the very questionable right of the individual citizen seriously to interfere with the amenities of a district by discharging to atmosphere the products of partial or even of complete combustion from the chimneys of his property. One has only to compare the effects on one's vitality of a day in the garden, the country, or the suburbs, with the effect of a day in the city, in order to realize the enormous cost to the national health and efficiency of the unrestricted and inefficient combustion of fuel, merely, in the majority of

cases, to enable the individual apparently to save a small percentage of his annual costs.

It is only necessary to recall the clarity of the atmosphere prevailing during the period of the General Strike of 1926 in order to realize that, in a well-regulated city, the inhabitants would not be allowed to indulge their individualism in the matter of the combustion of fuel at the expense of the general welfare. In fact, it may be confidently predicted that eventually the transport of fuel and ashes, with the resulting dislocation of essential traffic, will be prohibited through our streets, and that the combustion of both solid and liquid fuel will be centralized in licensed premises, zoned under town-planning schemes and operated under the strict supervision of combustion engineers.

(3) Value of Heat Insulation to the Structure.

It is now becoming generally recognized that the importance of the heat insulation of buildings is equal to or even greater than that of the warming installation and, just as no competent engineer would arrange for a tank or reservoir to be filled with water or oil until he had satisfied himself that all leakage had been entirely eliminated or at least reduced to the very minimum, so no electrical heating engineer should overlook the vital importance of taking the necessary steps to ensure that the heat leakage from the building will be reduced to the minimum by sound methods of construction, and also by the employment of suitable heat-insulating materials, such as granulated and slab cork, slag wool, moler bricks, diatomite, magnesia, etc.

The importance of this aspect of this subject is clearly demonstrated by a brief investigation of the construction of a £1 500 house considered from the thermal point of view. The bedroom ceiling area of a house of this type will probably be found to average 800 sq. ft., and for a roof construction of tiles on laths it may be safely assumed that there is a free passage of air through the roof, so that it is practically impossible to build up a temperature in the loft space over the bedroom ceiling. Naturally any tanks and water pipes which are located in the loft space will freeze when the outdoor thermometer falls to and remains at freezing point for more than a few consecutive hours—which in fact they do. It is even unusual to find the loft provided with a close-boarded floor over the entire area, and a moment's consideration will clearly indicate that the unfortunate occupants of the upper floor of a house of this type are only separated from freezing outdoor weather by a barrier of lath and plaster, approximately 0·75 in. thick, which in reality is nothing more than a wind screen. The effect on the electrical loading of improving the heat-insulating properties of the roof required to maintain 30 deg. F. difference between the indoor and outdoor temperatures is shown in Table 1.

Based on a price per kWh of 480 per £, and a normal annual consumption of 1 600 kWh per kW installed to maintain a temperature difference of 30 deg. F., the cost of the heat lost through the ceiling alone is £14 3s. 4d. per annum for the crude roof construction, as contrasted with £3 10s. 10d. per annum for the cork-insulated ceiling, so that a saving of £10 2s. 6d. per annum is effected by the introduction of heat insulation into the roof space. In fact, it is a very satisfactory $28\frac{1}{2}$ per cent investment on an initial outlay of £35.

For the steel-frame type of building, consider the flat roof and the ceiling of the top floor of a typical city office block of 20 000 sq. ft. For 6 in. of concrete, reinforced with steel, plastered below and laid with asphalt over, the coefficient of heat transmission may be taken as 0·28 B.Th.U. per sq. ft. per hour per degree F. difference between the two sides. For 30 deg. F. difference it would be 8·4 B.Th.U. per hour, and the total heat loss through the ceiling would be 168 000 B.Th.U. per hour, or 50 kW. Based on the normal annual consumption of 1 600 kWh per kW installed to maintain 30 deg. F. difference, the annual loss of heat through the ceiling will be 80 000 kWh. The introduction of a layer of slab cork 2 in. thick reduces the coefficient of heat transmission from 0·28 to 0·125 B.Th.U. per sq. ft. per hour per deg. F. difference. For 30 deg. F. the reduction is from 8·4 to 3·75 B.Th.U. and the total heat loss is reduced from 168 000 B.Th.U. per hour (or 50 kW) to 75 000 B.Th.U. per hour (or 22 kW), while the annual loss is reduced from 80 000 kWh to 33 000 kWh, a saving of 47 000 kWh, which at 480 kWh per £ represents a money value of £97 per annum, or a 14 per cent investment on a capital outlay of approximately £700.

Table 1.

Heat Losses through various Types of Tile Roof and Ceiling Construction.

Constructional details	B.Th.U. per sq. ft. per hour per deg. F. difference	B.Th.U. per sq. ft. per hour for 30 deg. F. difference	B.Th.U. per hour for 800 sq. ft. of ceiling area and 30 deg. F. difference	Equiv. watts for 800 sq. ft. for 30 deg. F. difference
Tiled roof on laths, no boards to laths, no floor to loft; lath and plaster ceiling	0·6	18	14 400	4 220
Tiled roof, rafters boarded one side, no floor to loft; lath and plaster ceiling	0·24	7·2	5 760	1 690
Tiled roof, rafters boarded one side, 2 in. cork slab with all joints closely sealed; lath and plaster ceiling ..	0·15	4·5	3 600	1 060

In regard to this very important question of heat insulation, it is understood that the electricity undertakers in New Zealand now regret that they did not take steps in the earlier stages of development to insist on adequate heat insulation of hot-water supply cylinders, because, had they done so, the present daily consumption of hot water could be supplied for probably 50 per cent of the actual energy consumption now metered, and the maximum demand on distributors, transformers, and

generating plant, would have been very materially reduced, while the revenue would probably have remained substantially the same, since the payment is invariably for services performed, the charge per unit being merely a convenient method of costing the service.

Walls and floors are just as amenable as ceilings to treatment with heat-insulating materials. An additional advantage of treatment of this character is that not only is the comfort condition maintained during the winter at a much lower cost, but, during the summer, the heat insulation is actively improving the comfort condition of the building by retarding the flow of heat into the building, thereby maintaining a lower temperature.

The principle of heat insulation is well established in connection with the construction of cold-storage chambers, but the advantages of its application to buildings maintained at a normal temperature does not appear to be equally well understood.

(4) Thermal-Storage Capacity of Building Materials.

The capacity of structural materials to store heat (i.e. their specific heat) is of great importance to the development of the electrical heating load, for, were it otherwise, heating "peaks" would be created, because consumers would use their warming equipment exactly as they do their lighting installations, switching it on only when they actually require the warmth, and switching it off immediately the warmth is no longer required. Fortunately, substantially constructed buildings (as contrasted with glass-houses, corrugated-iron structures, and the like) have a very marked thermal capacity, and if this fortuitous property is adequately utilized it will have a very marked tendency to smooth out the daily load curve of the supply undertaking.

In August, 1932, Dr. Oscar Faber published an article in which he gave interesting data for 15 London buildings, showing the number of floors, the total weight, the ground area, and the weight per sq. ft. of ground area. From this information the following data have been deduced in order to investigate the value of the thermal capacity of the structure and the effect on the electrical industry of an intensive development of the heating load.

(*a*)	Average site area	13 000 sq. ft.
(*b*)	Average number of floors ..	9·8
(*c*)	Floor area	127 000 sq. ft.
(*d*)	Volume	1 274 000 cub. ft.
(*e*)	Rate of heat loss calculated on the basis of 0·45 watt per cub. ft.	573 kW. (For a thermal-storage plant of 80 per cent heater and distribution efficiency and 12 hours supply period, the daily maximum load would be 1 430 kW.)
(*f*)	Rate of heat loss per sq. ft. of site area (calculated on the basis of 0·45 watt per cub. ft.)	44 watts (110 watts for thermal-storage plant as above)
(*g*)	Annual consumption, at 2 000 kWh per kW of heat loss	1 146 000 kWh or 0·9 kWh per cub. ft. per annum)
(*h*)	Annual revenue at 1 000 kWh per £1	£1 146
(*j*)	Gross weight of building, including superimposed floor load	23 000 tons
(*k*)	Net weight of structure, based on a ratio of gross to net (i.e. deducting the superimposed floor load at 50 lb. per sq. ft.) of 82·5 per cent	19 000 tons (1·46 tons per sq. ft. of site area) or 42·5 million lb.
(*l*)	Heat required to raise a $42\frac{1}{2}$ million lb. structure through 1 deg. F. (based on an average specific heat of the materials of 0·2)	$8\frac{1}{2}$ million B.Th.U., or 2 500 kWh
(*m*)	Ratio of line (*l*) to line (*e*)	4·34

It is interesting to note that the average load is of the order of 573 kW net or 1 430 kW gross, the annual consumption 1·15 million kWh, the possible revenue £1 146 per building, and that *the heat required to raise the temperature of the structure through* 1 *deg. F. is some* 4·34 *times the heat required per hour to maintain the temperature of the structure when the outdoor temperature is at freezing point.*

Closely related to this large quantity of heat that is required to warm up the structure in the initial years, there is the heat required to evaporate the water employed in mixing the mortar, concrete, plaster, etc., and absorbed by the structure during the time that it is exposed to the weather. As each gallon of water weighs 10 lb. and the latent heat of evaporation at 45° F. is 1 050 B.Th.U. per lb., each gallon requires practically 3 kWh to evaporate it. Therefore, if the water to be evaporated from the structure during the initial heating seasons amounts only to 1 per cent of the total weight of the building (i.e. of 19 000 tons or 42·5 million lb.), the actual weight is 425 000 lb., the gallons 42 500, and the kWh required to "dry out the building" would be of the order of 100 000, allowing for 20 per cent to be removed from the external surfaces of the walls by the sun and wind.

(5) Effect of the Various Types of Electrical Warming Systems on the Distributing Network and on the Load Factor.

In his 1931 paper* one of the present authors directed attention to the varying efficiency values obtainable with different types of warming equipment, and pointed out that the problem was not that of pouring an unlimited quantity of heat units into the building, but of maintaining the comfort condition with the minimum consumption of energy, and Barker† presented a detailed analysis of the efficiency values obtainable with different fuels and systems of heating.

In a previous paragraph it has been shown that the structure has a substantial capacity for storing heat and

* See Bibliography, (2).

† *Ibid.*, (3).

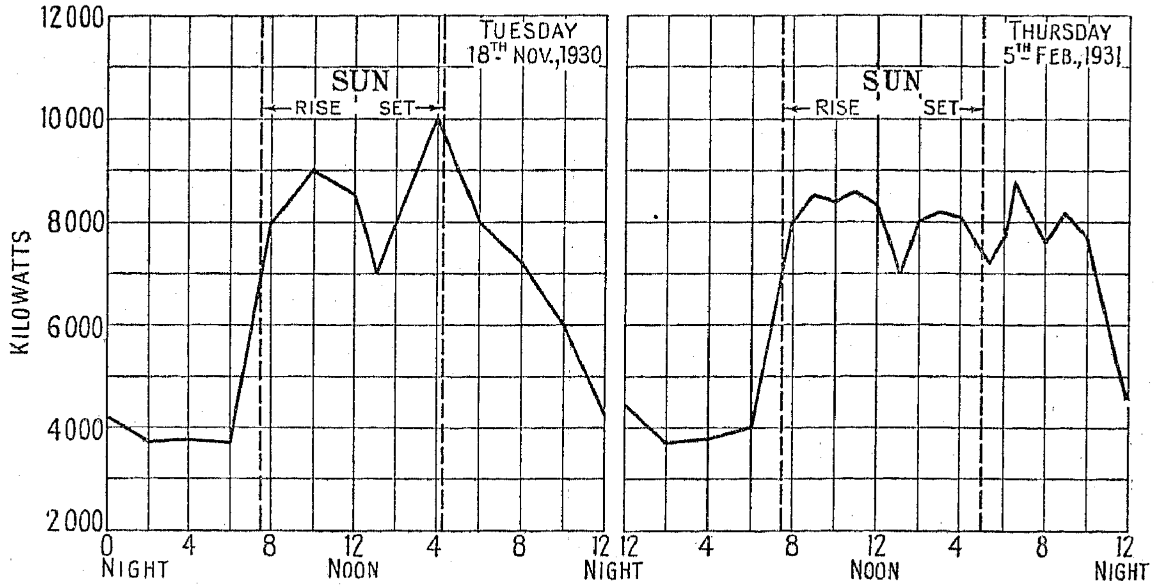


FIG. 1.—Typical daily load curve for November and February.

it therefore appears to be illogical to permit it to cool down during the night, when energy is available at very low rates, and then to endeavour to produce the comfort condition either instantaneously or very rapidly just at the time (6.30 a.m. to 11 a.m.) when the demand for energy is rapidly rising to provide the requirements of lighting, cooking, water-heating, traction, factory power, etc., and when the cost of supply is practically at its maximum value. By the kindness of Mr. R. W. L. Phillips of Bedford, it has been possible to reproduce a typical daily load curve for the Bedford area of supply (where the domestic load has been well developed), and the effect of superimposing a time-controlled heating load reaching its maximum between the hours of 6.30 a.m. and 11 a.m. is worthy of study (see Fig. 1).

Although the subject is held by many people to be a highly contentious one, the leading firms of heating engineers, who have experience of hot-air furnace, fan heater unit, sectional cast-iron radiator, pipe coil, high- and low-temperature wall and ceiling panel, and low-temperature floor panel, warming systems, are definitely of the opinion that a low-temperature ceiling-panel system of warming shows an economy in fuel consumption of some 25 per cent, both in boiler capacity and in operating costs, over sectional cast-iron radiator, pipe, and other convection systems of warming.

Regarding the question of intermittent versus continuous heating for buildings of substantial construction (as contrasted with glass-houses, corrugated-iron and similar structures of negligible thermal capacity) it is generally agreed that for buildings intermittently heated the loading must be increased by from 15 to 40 per cent, depending on the extent of the intervening periods of cooling, and this again is reflected in the value of the time-controlled load.

Experience shows that although it is possible for the direct heating systems, operated under the control of thermostats to the individual rooms, to demand a peak of 60 per cent of the connected load during the day, it seldom if ever occurs in occupied buildings because of the higher temperatures prevailing during the day, and also by reason of the casual heat introduced into the warmed space by the radiant heat of the sun, the occupants, the lighting equipment, and other sources. In this connection it has already been pointed out that the heat from the lighting load of many modern buildings is equal to and not infrequently exceeds the heating requirements, and it is understood that this theory has received ample

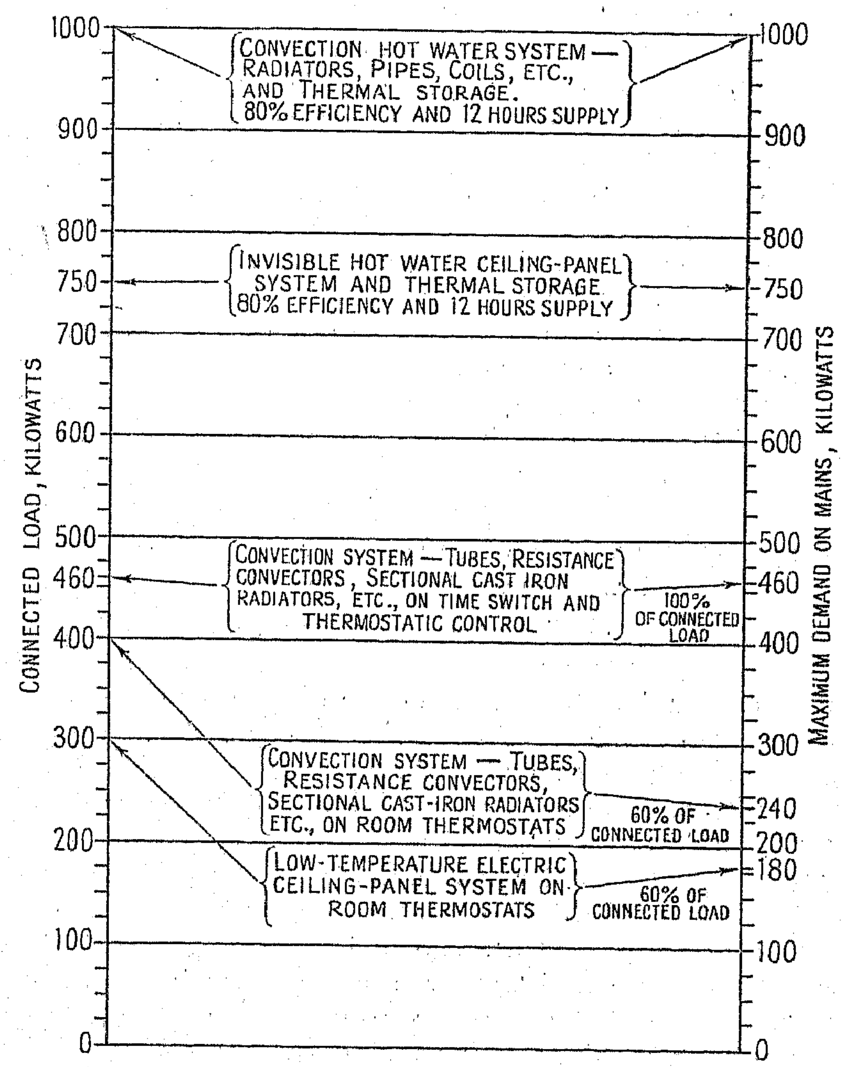


FIG. 2.—Relative loadings for various methods of electric warming for a building, the heat loss being calculated to be 1 million B.Th.U. per hour, or 294 kW.

support at the Building Centre in Bond Street, where the comfort problem has resolved itself into one of cooling rather than of warming the building, due entirely to the heat emitted by the lighting equipment and by the visitors and staff.

In order to summarize the effect of the various types

of electrical warming systems on the electrical distributing system, Fig. 2 has been prepared for a building for which the energy required to offset the heat loss for a 30 deg. F. rise for an invisible embedded electric ceiling-panel system has been calculated to be 1 000 000 B.Th.U. per hour, or, in round figures, 300 kW. Averaging the load on the individual room thermostats at 2 kW, and assuming that 60 per cent are closed simultaneously, the maximum load on the mains becomes 180 kW. For a convection system of tubular heaters or sectional cast-iron radiators equipped with immersion heaters, the connected load would be of the order of 400 kW. If this is controlled by 200 thermostats the maximum load on the mains should not exceed 240 kW, but if it is switched off each night and on each morning by means of a time switch, then the 400 kW load would be increased by (say) 15 per cent, making a total of 460 kW, and on cold mornings the full load would be switched on to the mains, all the thermostats being closed after the long run through the night without any heat being available to maintain the temperature. After the building had warmed up again the load would drop to the normal of 240 kW on cold days. For an invisible water panel system with thermal storage, if the overall efficiency between heat input to the storage vessel and to the individual rooms is 80 per cent and the supply period is 12 hours, the demand will be increased to 750 kW, and for a sectional cast-iron radiator or pipe coil system of the thermal-storage type, given a similar efficiency (although the temperature of the water in the distributing pipes will be 60 deg. F. higher) and charging period, the demand on the mains will be increased to 1 000 kW.

These are the facts of this aspect of the subject as the authors see them, and it is a question for the engineers in the supply section of the industry to decide which type of load they desire to develop and to frame their tariffs accordingly.

(6) Intermittent Warming of a Few Rooms in a Partially Occupied Building.

Another aspect of the "intermittent versus continuous warming" controversy is the intermittent use of a few rooms in a building, the remaining rooms being continuously occupied. The view very generally expressed is that such rooms should only be warmed when they are actually required for use, and that at all other times the heat should be switched off. In order to investigate the question with a view to tendering definite advice, a detailed investigation of a certain building was made; the results obtained are shown in Table 2. It will be seen that for the satisfactory adoption of the intermittent method it would be necessary to instal 21 per cent additional surface, thereby increasing the total surface installed from 1 078 to 1 304 sq. ft. in order to offset the heat losses through the internal walls to the intermittently warmed rooms. Again, if the rooms are to be intermittently heated, the cooling period being extended to several days, the surface in those rooms will also require to be increased by at least 15 per cent to enable the temperature to be quickly raised when required.

A detailed calculation of the annual operating cost was made and it was found that if several of the rooms were intermittently warmed, and the additional heat for rapid boosting and the losses through the internal rooms were included, the estimated annual saving was less than £2. The proposal was therefore abandoned and continuous warming resorted to.

(7) Estimating the Annual Consumption of Electricity, Gas, Coke, and Oil.

The generally recognized "official" heating season extends from the 1st October to the 30th April, a total of 212 days or 5 088 hours, or, in round figures, say 5 100 hours. The mean indoor temperature usually required in residential and office buildings is 63° F. and the mean outdoor temperature for the London area for the 212-day period is 44° F., so that the mean temperature-rise required is (63 — 44) or 19 deg. F. If the installation is designed to maintain 63° F. indoors when the outdoor temperature is 30° F., then the average load on the warming installation is $19 \times 100/33$ or 57·5 per cent, and the equivalent hours' use of the maximum power will be 57·5 per cent of 5 100 hours, or 2 940 hours.

For hand-fired coke-boiler installations without automatic temperature control, where the tendency is to maintain a temperature slightly in excess of the scheduled temperature in order to avoid complaints, the value usually taken is 66 per cent of 5 100 hours, or 3 400 hours full-load operation. With centralized temperature control and a certain amount of casual heat it is usual to calculate on the basis of 2 900 hours, and for thermostat control to the individual rooms values of from 2 000 down to 1 600 hours will usually be found to give reasonably accurate results.

The calorific value of coke can be taken to be 12 500 B.Th.U. per pound or 28 million B.Th.U. per ton, oil at 19 300 B.Th.U. per lb. or 44 million B.Th.U. per ton, and a gas therm = 100 000 B.Th.U.*

These are the fundamental data employed in the construction of the graphs reproduced in Figs 3, 4, and 5, the efficiency values appearing below each chart being reproduced from Mr. Barker's paper (see Figs. 3, 4, and 5).

In America the term "degree-days" is becoming popular and it has certain advantages. If the mean temperature-rise required throughout the heating season is 19 deg. F. and the total number of days on which heat is required is 210 days, then the total number of degree-days will be practically 4 000, and a very simple table of annual consumption can be constructed on this basis.

(8) Effect of the Grid Tariff on Contracts for the Supply of Electrical Energy.

Fig. 7 has been prepared to show the approximate cost of the grid supply to the authorized distributor, based on a fixed charge of £3 5s. per kVA of maximum demand and a running charge of 0·21d. per unit metered. To obtain a reasonable selling price to the consumer, the

* Prices in London on the 1st October, 1934, for solid fuel suitable for automatic-feed stokers were: Anthracite beans, 39s. 9d.; anthracite peas, 35s. 9d.; Warwickshire peas, 27s. 4d.; Scottish washed peas, 26s. 6d.; Eastwood washed smalls, 26s. 4d. per ton; also anthracite grains (13 600 B.Th.U.) 29s.; Scotch washed peas (12 000 B.Th.U.) 25s.; Yorks washed peas (12 500 B.Th.U.) 26s. per ton for 300–500-ton contracts.

TABLE 2.

Extra Surface Required in a Building in which Several Rooms are Intermittently Warmed.

Floor	Name of room		B.Th.U. required per deg. F. difference					Temp. rise	Heating surface required		Extra surface	Total heating surface required
			Air	Floor	Glass	Wall	Roof		External losses	Internal losses		
								deg. F.	sq. ft.	sq. ft.	per cent	sq. ft.
Ground	Lecture Hall ..	External	—	185	550	156	—	35	260	..	14	297
		Internal	—	163	—	19	112	15	—	37		
First	Clerk's Room ..	External	47	—	72	45	—	35	49	—	14	56
		Internal	—	58	—	—	—	15	—	7		
First	Secretary	External	40	—	72	45	—	35	46	—	30	60
		Internal	—	53	—	24	37	15	—	14		
First	Small Hall ..	External	71	—	150	54	—	35	80	—	38	110
		Internal	—	91	—	147	—	15	—	30		
First	Council Room ..	External	120	—	160	155	—	35	126	—	33	168
		Internal	—	154	—	46	136	15	—	42		
Second	Ante-room ..	External	21	—	64	12	30	35	37	—	30	48
		Internal	—	18	—	67	—	15	—	11		
Second	Principal Assistant	External	35	—	70	27	49	35	53	—	8	57
		Internal	—	22	—	7	—	15	—	4		
Second	Second Assistant ..	External	79	—	72	42	56	35	73	—	16	84
		Internal	—	—	—	85	—	15	—	11		
Second	Third Assistant ..	External	79	—	72	42	56	35	73	—	6	77
		Internal	—	—	—	32	—	15	—	4		
Second	Class Room 1 ..	External	70	—	96	22	49	35	69	—	30	90
		Internal	—	43	—	123	—	15	—	21		
Second	Class Room 2 ..	External	132	—	120	55	94	35	117	—	20	141
		Internal	—	54	—	132	—	15	—	24		
Second	Class Room 3 ..	External	108	—	96	45	76	35	95	—	22	116
		Internal	—	45	—	121	—	15	—	21		
	Totals ..								1 078	226	21	1 304

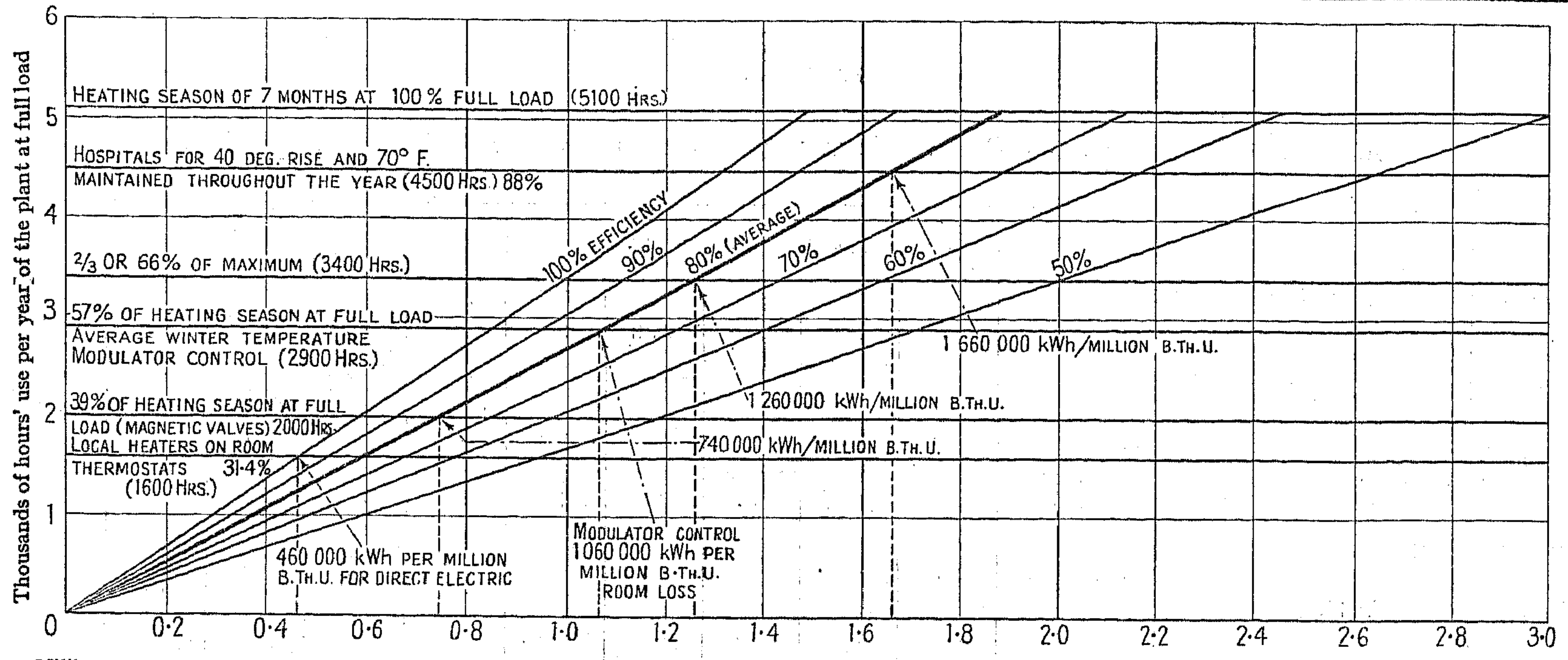


Fig. 3.—Graph for estimating the annual consumption of electrical energy for thermal storage and for direct electrical heating installations. (Graph to be used for the heating installation only; the annual consumption for ventilation and hot-water service to be estimated separately.)

Example.—Given that for a thermal-storage system, under the control of a single flow-thermostat, the building loss is 300 000 B.Th.U. per hour, then the annual consumption should be equivalent to 2 900 hours' run at full load, and if the combined efficiency of heater, storage vessel, and pipework is taken to be 80 per cent, it will be at the rate of 1 060 000 kWh per million B.Th.U., and for 300 000 B.Th.U. it will be 318 000 kWh.

Table of Efficiencies (Barker).

Grade	Boiler	System	Combined
Best	98	90	88
Medium	95	75	71
Worst..	90	50	45
Local electric heaters			100

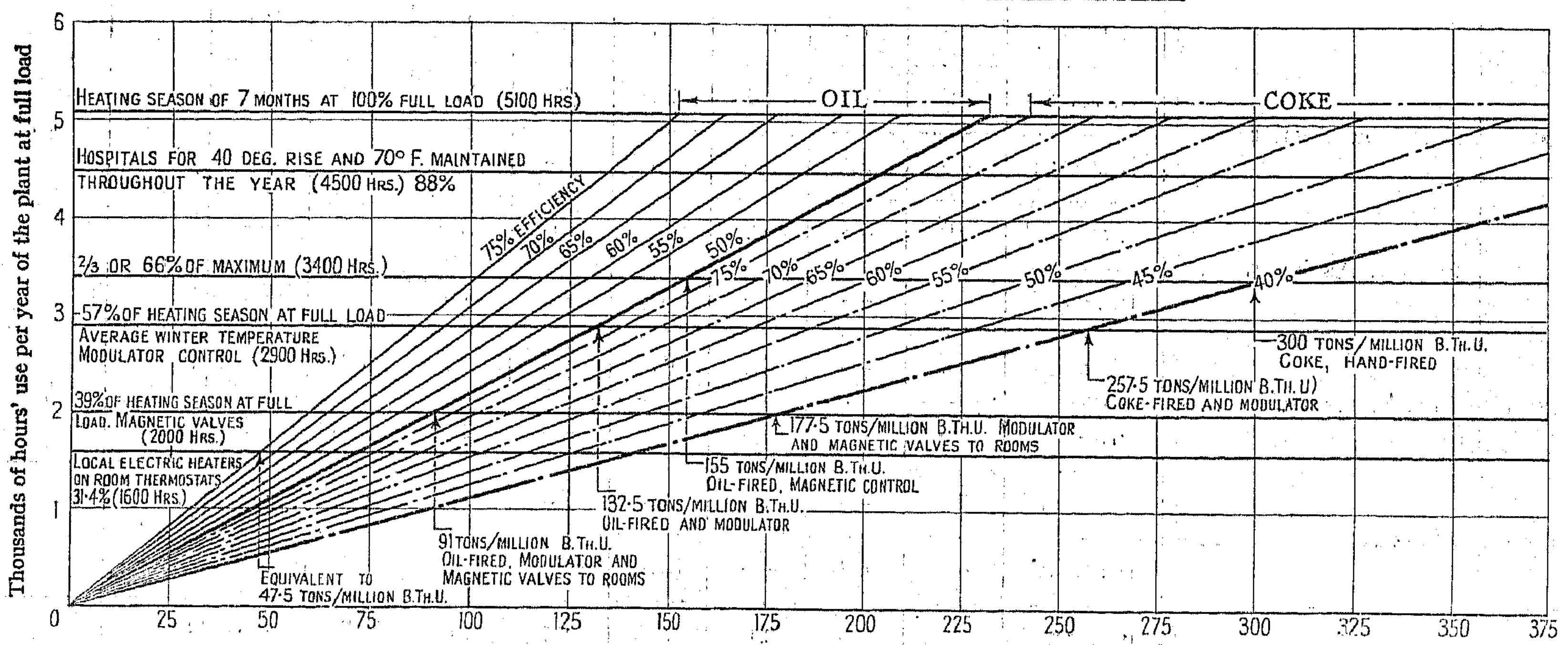
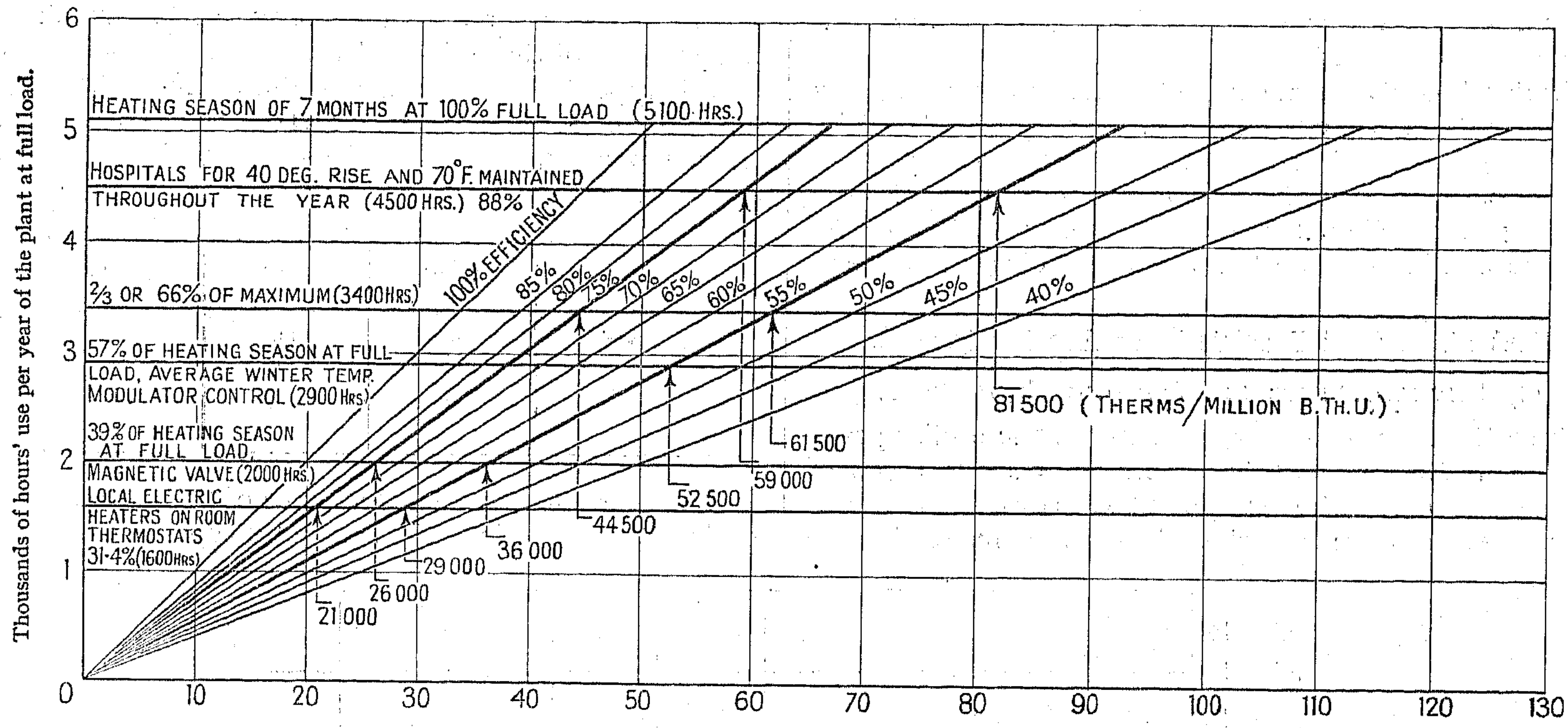


Fig. 4.—Graph for estimating the annual consumption of solid and liquid fuel for central hot-water heating installations. (Graph to be used for the heating installation only; the annual consumption for ventilation and hot-water service to be estimated separately.)

Table of Efficiencies (Barker).

Item	Best	Medium	Worst
Coke boiler	75	55	35
System	90	75	35
Combined	68 (= 70)	41 (= 40)	12
Oil boiler	80	65	50
System	90	75	35
Combined	72 (= 70)	49 (= 50)	18

Coke based on 12 500 B.Th.U. per lb. (28 million B.Th.U. per ton)
Oil based on 19 500 B.Th.U. per lb. (44 million B.Th.U. per ton)



Thousands of therms per year per million B.Th.U. per hour required to maintain the specified temperature within the building when the outside temperature is 30° F. (1 therm = 100 000 B.Th.U.).

FIG. 5.—Graph for estimating the annual consumption of gas for a gas-fired central hot-water heating installation. (Graph to be used for the heating installation only; the annual consumption for ventilation and hot-water service to be estimated separately.)

TABLE OF EFFICIENCIES (BARKER).

Grade	Boiler	System	Combined
Best	85	90	76
Medium	75	75	56
Worst	65	60	33

probable diversity of demand requires very careful consideration, and there require to be added appropriate allowances to cover the transformation and distribution losses, administration costs, capital charges, and profit.

A very brief examination of this graph will indicate that diversity of demand is the only possible way either to quote or to secure a low price per unit, i.e. of the order of 500 to the £ for unrestricted supply or 1 000 to the £ for restricted-hour supply. In this connection it may be mentioned that a point that has frequently puzzled the authors is the reluctance of many supply authorities to adopt the two-rate tariff for the unrestricted, thermostatically-controlled, heating load, the night consumption being charged at rates between 500 and 1 000 units to the £.

An interesting contract recently discussed with a particularly keen supply authority provided for electricity to be used for all purposes, the energy for heating and hot-water supply being restricted to 19 hours per day—not necessarily continuous but probably with two breaks of three and two hours respectively, and under their control by means of pilot wires—all units metered for whatsoever purpose being charged at the rate of 960 to the £. The total fixed charge payable would be £1 250 per annum, and, at the request of the consumers, a long-term contract was offered. It appears highly probable that, after the closest investigation of the various methods and combinations of methods of providing light and heat for the building, the electrical method will be adopted.

Another type of (at present) unusual contract was reported in the *Electrical Review* of the 4th May, 1934, in the following terms: " The Ministry of Health is prepared to approve the all-electric scheme if the annual charge for heating and steam as from the opening of the baths is fixed at £2 100, subject to variations of fuel costs, etc., which it regards as comparable with the annual

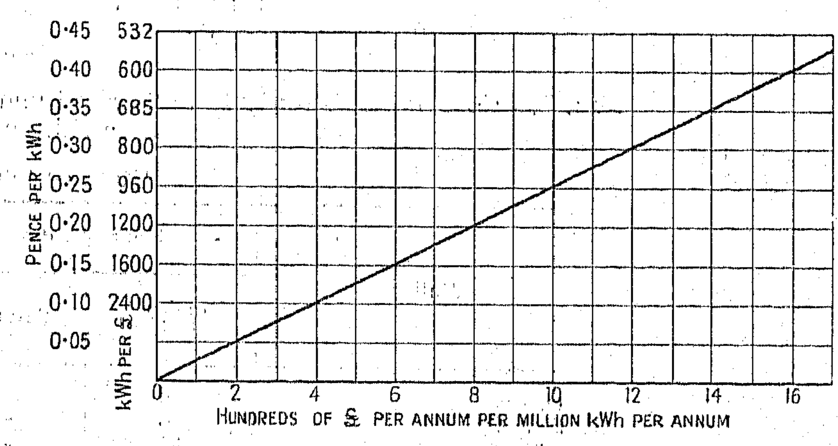


FIG. 6.—Annual cost of electrical energy at various rates per kWh.

charges for a coke-fired installation. The Committee accordingly recommends that the inclusive charge to the general account for all electric supplies to the new Seymour Place (St. Marylebone) public baths, as from the opening of the premises, should be £2 600 inclusive, being £2 100 for heating and steam requirements and £500 for lighting and other uses, subject to variations for

fuel costs and subject also to the charge being reviewed annually thereafter."

Similar "fixed annual charge" contracts are now being offered by the gas companies, one recently completed for a building in the West End of London being at the rate of £500 per annum for heating and hot-water supply, the building and boilers being under thermostatic control, and the minimum room temperatures being guaranteed.

Part II. Direct Electric Warming Equipment.

(1) Developments in Warming Equipment.

Since the date of the presentation of the earlier paper by one of the authors* in which the various types of direct electric warming equipment were discussed at some length, substantial progress has been made in the direction of improved design and in the technique of application, but there is no fundamental change to report.

Considerable attention has been paid to the "panel" form of heater operating at temperatures of the order of 200° F.–250° F., while the rating of the fabric type (designed for pasting to the ceiling) has been lowered to 18 watts per sq. ft. with a corresponding maximum temperature of the order of 75° F.–90° F.

Unit-type thermal-storage heaters having bodies of soapstone enclosed in lagged metal cases have been placed on the market, the dimensions and ratings being as shown below:—

Rating	Width	Depth	Height
kW	in.	in.	in.
3	29	8¾	24
4	33	10½	28

It has been a common experience of the authors, when designing installations of the tubular type, to find that it is not possible to provide the heat required from a single line of tubes, and where "double banking" has been objected to on the score of appearance the balance of surface required has been provided by means of electric hot-water "radiators" of the immersion-heater type, electric fires, or panels of the low- or medium-temperature type.

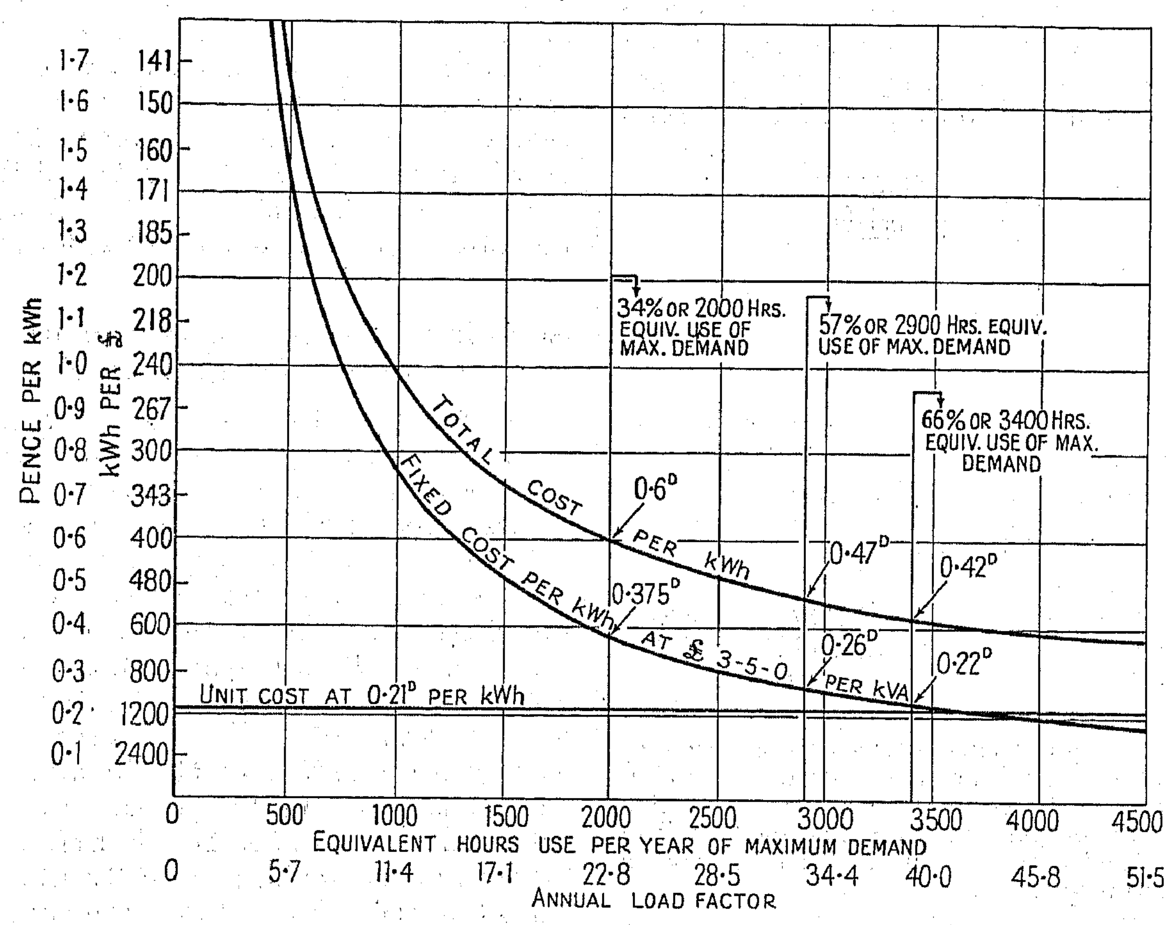


Fig. 7.—Cost of grid supply to authorized undertakers at £3 5s. per kW of maximum demand and 0·21d. per kWh metered.

Occupied Hours per Season.

Building	Hours per day: Monday to Friday	Hours per day: Saturday	Hours per week	Weeks per season	Hours per season
Offices	9	4	49	29	1 420
Schools	6	—	30	25	750
Residence	24	24	168	30	5 040
Factory	8	4	44	29	1 280

* See Bibliography, (2).

(2) Developments in Temperature-Control Equipment.

The heating of the working parts of a thermostat, due to the passage of current through them, has hitherto been regarded as a vice rather than as a virtue, so that if the heating equipment which they are provided to control has low thermal capacity it will operate at or near its maximum temperature even on mild days, the temperature control of the room being effected by comparatively short "on" periods, followed by comparatively long "off" periods. Conversely, if heat is intentionally introduced or developed in the thermostat whenever it closes the circuit, it will open prematurely in relation to the room temperature, and when the local heat has been dissipated it will again close and commence to warm up, the cycle being repeated until such time as the predetermined room temperature has been attained. With the aid of this "chopper" type of thermostat it should be possible to operate the warming surface at comparatively low temperatures during periods of mild

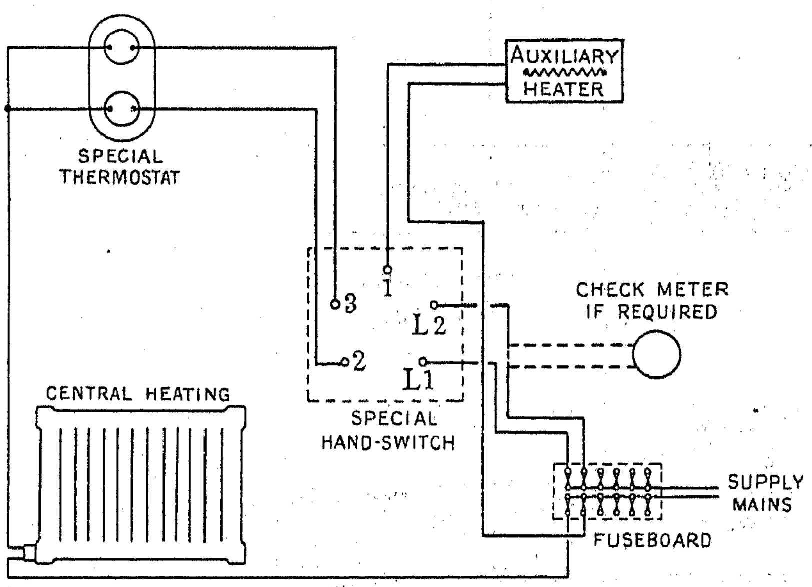


Fig. 8.—Arrangement of connections, thermostats, and switch, to the heater of a central heating system and to an auxiliary or local electric boosting heater or fire. (For use where a basic temperature is maintained by the building owner and the tenant requires a higher temperature intermittently.)

weather, and at substantially higher temperatures during periods of severe weather, since the rate of cooling will be more rapid in cold weather and the "on" intervals will be much more closely spaced.

Another aspect of temperature control arises in connection with buildings that are particularly suitable for the "intermittent," as contrasted with the "continuous," method of warming, and it may be found convenient or economical merely to lower the temperature at night or to switch the heating off entirely. Certain circuits may be switched off by means of time switches, or duplicate thermostats and circuits may be employed, one set being adjusted for the "day" temperature and the other for the "night" or "unoccupied" temperature. Again, the voltage may be "bucked" or "boosted" by means of a central control. In many of these cases a combined time and temperature control is required for the heating-up period, as this naturally varies with the outdoor temperature, i.e. during periods of mild weather the warming-up period may only extend to one or two hours, whereas during the prevalence of severe weather the period required to warm the building may extend to many hours, so that the hour of switching-in must be automatically adjusted by the outdoor temperature.

Many buildings of the "flat" or "apartment" type are now being erected in which the landlord undertakes to maintain a basic temperature of 55, 58, 60, 62, or 65° F. in certain scheduled rooms, and if and when the tenant requires a higher temperature he must provide the additional heat at his own expense. In these circumstances the control of the landlord's or basic heating equipment by means of the ordinary thermostat and circuit wiring does not achieve the purpose in view, because immediately the tenant's supplementary heater raises the temperature above the basic value of 55° F. or other agreed figure, the landlord's thermostat cuts out and the whole load is taken over by the supplementary heater. To meet these special conditions, it becomes necessary to provide a special thermostat and a special switch interlocked with the tenant's supplementary heater in such a manner that the higher temperature can only be obtained when the basic and the supplementary heaters are both in use (see Fig. 8), the kWh used by the latter being registered on the tenant's meter.

(3) Tariffs for the Development of the Thermostatically-Controlled Heating Load.

Fig. 9 shows the "day" and "night" consumption for a period of 26 weeks of a ground floor and basement suite, occupied as a shop, office, and stores, in the West Central district of London. The installation is of the hot-water "radiator" type, equipped with immersion heaters, and is operated on the "continuous" system, the thermostats being set to maintain temperatures averaging 63° F. throughout the heating season. The volume to be heated is 30 500 cub. ft. and the installed heating load 19·7 kW. Unfortunately, the water-heating consumption of the lavatory basins, cleaning, etc., is included in the weekly record from the 3rd November, but this has been estimated at 1 500 kW for the season, and would practically all be used during the "day" period. The net heating consumption metered for the period was 21 777 kW, or at the rate of 1 100 kWh per kW of the *connected* load. The "day" meter registered 9 772 kWh, and the "night" meter 13 505 kWh. It is interesting to note that 50 per cent of the possible "night" consumption was only reached during one week, and that 50 per cent of the possible "day" consumption was only reached during two weeks of the period.

The question for the consideration of the distributing authorities is whether installations of this type are entitled to preference over the electric fire load, which is essentially a "day" load although admittedly of a highly diverse character in districts of the residential type. Several distributors are now quoting "day" rates of the order of 320 kWh per £, and "night" rates of the order of 480 to 535 per £, and appear to be very satisfied with the results, but before the method becomes really popular the units will require to be sold at 500 and 1 000 to the £ for the "day" and "night" units respectively.

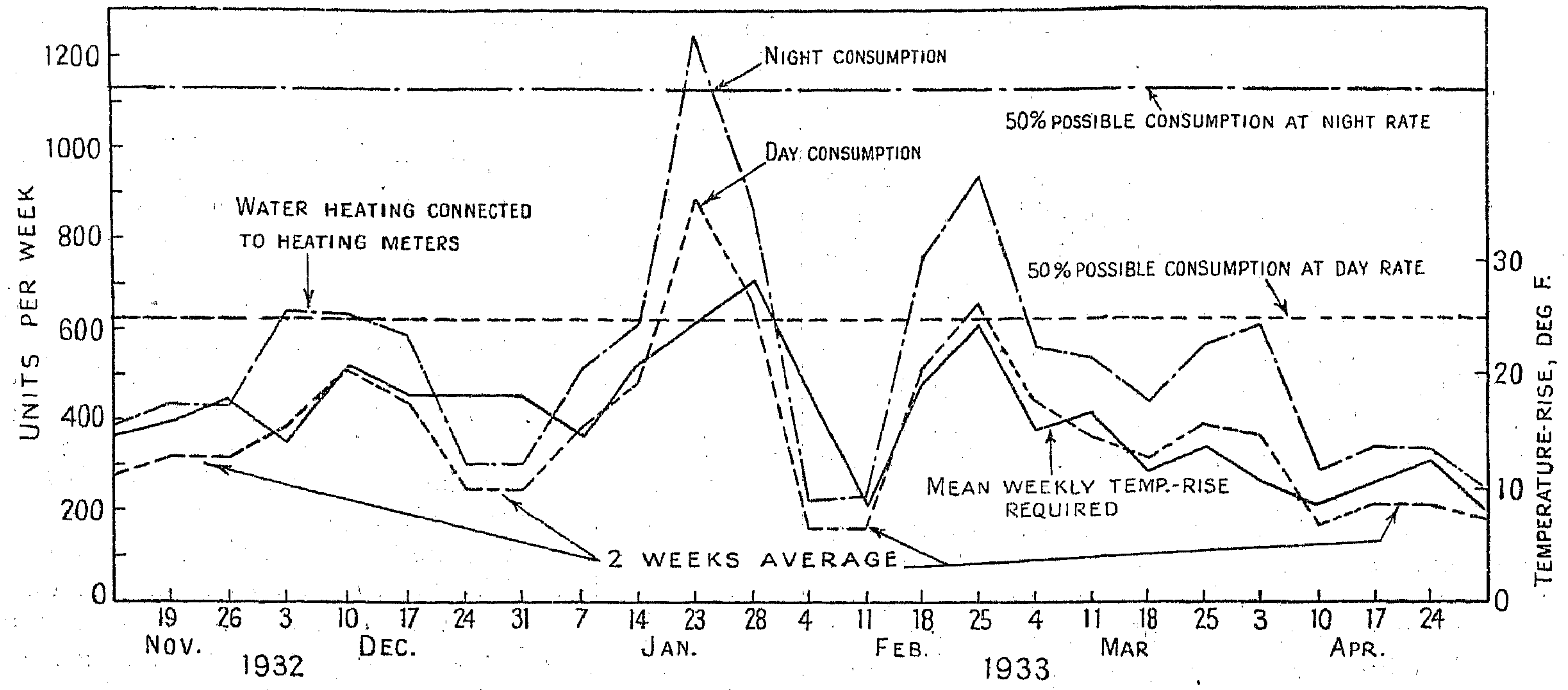


FIG. 9.—Graph of day and night consumption of 20-kW direct electric heating installation under the control of individual room thermostats. (" Day " rate between the hours of 10 a.m. and 7 p.m., and " night " rate from 7 p.m. to 10 a.m.)

NOTE.—The values for temperature-rise plotted on the right-hand ordinate and shown by the full line are obtained by deducting the mean outdoor temperature for the week from the mean indoor temperature maintained (e.g. 63° — 43° = 20 deg. F. rise).

Part III. Thermal-Storage Equipment.

Section I. DETAILS RELATING TO IMMERSION AND ELECTRODE HEATER EQUIPMENT.

(1) DEFINITION OF TERMS.

The equipment employed for heating water electrically may be broadly divided into two groups or categories as follow:—

(*a*) The metallic resistance type which is insulated from the water, the heat being transmitted from the resistance to the water through the containing tube of metal.

(*b*) The electrode type, in which the water itself carries the current and acts as the resistance.

In both cases the heating equipment is naturally immersed in the water, and, in this sense, both types are *immersion* heaters. Common usage has, however, reserved the term " immersion heater " for equipment of the former type, while the term " electrode heater " has been applied to the latter.

For steam-raising purposes the heaters are termed " electrode boilers," but if they are used merely for heating water for use in low-pressure hot-water heating or hot-water supply systems, then the term " electrode water heater " is generally employed to describe them. Immersion heaters are not generally employed for steam-raising purposes in this country, although they are listed by at least one Continental manufacturer.

In general, the immersion heater is used on low voltages (up to 250 volts) and medium voltages (250–650 volts), while the electrode type may be used either on medium-voltage or high-voltage networks direct, subject to the special approval of the Electricity Commissioners.

(2) DETAILS RELATING TO IMMERSION HEATERS.

Immersion heaters may be grouped into the following broad types:—

(*a*) Blade type.
(*b*) Tubular type.

As the life of electric heating elements operating at high temperatures must, of necessity, be regarded as limited, facilities for rapid and comparatively inexpensive replacement are usually regarded as essential. Although this virtue has been claimed for several types of the blade form of heater, the experience of users does not tend to confirm this claim for them after a year or so of service. Again, the operating temperature of an electric heater when on load only becomes constant when the energy input is balanced by the heat output, and in the blade form of heater the latter condition varies with the angular rotation of the blades. If the heaters are fixed in the side of a vessel and are rotated on a horizontal axis until the longer sectional axis is in the vertical position, then the convection current of water and the cooling effect are at their maximum value. Conversely, if the blade is rotated until the longer sectional axis is in the horizontal position, then the convection current of water and the cooling effect are at their minimum value, and the temperature will rise until the point of balance is again reached. To economize space on the faceplate when the heaters are grouped, screwed joints are used in preference to flanged joints, in order to permit of the ready replacement of the combined heater and enclosing tube, and it will be readily understood that the vertical position and a watertight joint cannot be simultaneously guaranteed when the static head of water is of the order of 130 ft. or 57 lb. per sq. in. Quite naturally, the fitter pays more attention to the leakage of water, which is obvious, than to the angular position of the blades, which cannot be seen.

For the foregoing reasons, and also because of the difficulty that is frequently experienced in withdrawing the elements from the blades of the flat type of heater, the tubular type is rapidly becoming recognized as standard practice.

A heavily tinned, solid-drawn steel tube having a bore of 2 in. and a wall of 18 S.W.G. is found to give satisfactory service, so that the external diameter becomes

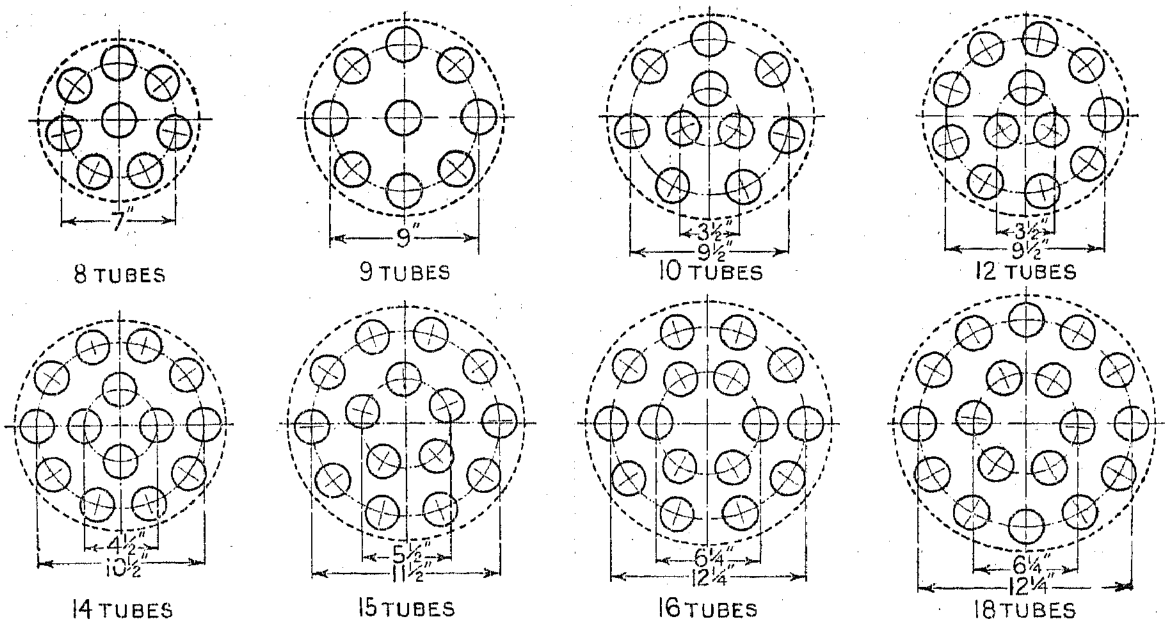


FIG. 10.—Grouping and dimensions of immersion heaters for various loadings.

NOTE.—At 10 watts/sq. in. of tube surface, the length of the heater from the water side of the faceplate to the end of the tubes is: 3 kW, 4 ft.; 4 kW, 5 ft. 4 in.; 5 kW, 6 ft. 8 in. If a "de-loaded" section is required next to the faceplate, this length must be added to the dimensions given.

practically 2·1 in., the circumference 6·6 in., and the area 6·6 sq. in. per inch of length of the tube. The loading per sq. in. of tube varies with different makes, but long life is now being secured with values of the order of 10 to 12 watts, with an upper limit of 15 watts per sq. in. Heaters which have given satisfactory service when banked into groups up to a total of 100 kW are analysed in Table 3.

It is usual to brace or connect together the ends of the tubes remote from the faceplate, and to provide an adjustable support or crutch, the toe of which rests on the bottom of the vessel into which the heaters are inserted. In hard-water districts mild steel faceplates may be used and, for the larger groups of heaters, they should have a minimum thickness of $1\frac{1}{8}$ in., the tube holes in the plate being grooved and the tubes expanded into the plate. In soft-water districts, gunmetal plates are used. To maintain a watertight joint, close spacing of the fixing bolts is essential, as the full temperature gradient of from 150 to 200 deg. F. moves across the plate each day, i.e. the upper edge may be at 250° F. while the lower edge is at 100° F. To ensure a good flow of water between the tubes, the units should be spaced on a minimum of $3\frac{1}{2}$-in. centres (see Fig. 10).

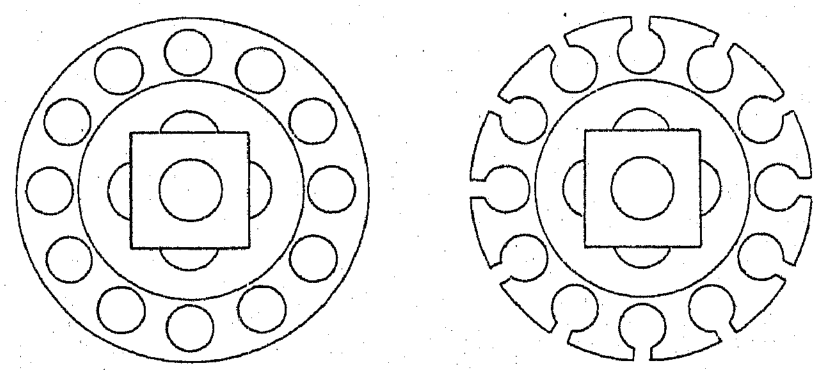
TABLE 3.

Loadings per Square Inch of Immersion Heaters.

Rating	External diameter	Circumference	Length	Area	Loading per sq. in.	Current at 230 volts
kW	in.	in.	in.	sq. in.	watts	amps.
1	2·1	6·6	12·5	82·5	12·2	4·33
2	2·1	6·6	24·25	159·5	12·6	8·7
3	2·1	6·6	36·25	240	12·5	13
4	2·1	6·6	48·25	318	12·6	17·4
5	2·1	6·6	60·5	399	12·6	21·7

Regarding the type of insulator or former employed to support the resistance wire, there exist two schools of thought, one favouring the open type of slot, and the other preferring the closed type of slot (see Fig. 11). The authors have successfully used both types, but have a decided preference for the closed type, for, in the event of a break in the wire or of rust forming in the tube, there is then less risk of contact between the wire and the metal containing element-tube, with the further risk of the contact, thus established, burning a hole in the tube and allowing a serious leakage of water to occur.

Although several makers can show 400-volt heaters in successful operation, there appears to be a very distinct preference for the 230-volt unit, as it is considered that the space factor in a 2-in. tube is insufficient to ensure the maximum of reliability with the bare element, under the very severe operating conditions that are inevitable within the tube. Further, no apparent material advantage is gained by the use of the higher phase voltage for the individual heaters, since the phase current on the balanced group is the same in both cases, so that the only additional expenditure involved by the use of the 230-volt unit is the introduction of the neutral conductor. It is desirable to provide a neutral connection in any event for the operation of the thermostats and the contactor gear, and contactors are of the triple-pole type for both voltages.



A B

FIG. 11.—Formers for the elements of immersion heaters.
A.—Totally enclosed slot. B.—Semi-enclosed slot.

The limit to which bunching or grouping of the heater tubes on a plate may be extended depends to a large extent on the method adopted for protecting the individual heaters against overload, and also on the maximum load that can be switched without risk of undue interference to the voltage regulation on the local network. The former restriction is discussed in the Section dealing with control, and the latter is a matter for arrangement with the supply authority.

The busbars required to distribute the current to the individual heaters preferably take the form of rings carried on supports which, in turn, are fixed at right angles to the faceplate. Connections between the busbars and the heater terminals are conveniently made by means of tinned copper or monel metal tails insulated with fish-spine beads, and the arrangements of tails and busbars should be such that any element may be withdrawn from its tube without disturbing any part, other than disconnecting the tail from the busbar.

Care must be exercised in the form of connection employed between the actual element wire and the flexible tail, for experience shows that it is not sufficient merely to bring out a nickel-chrome wire carrying from 10 to 20 amperes, to twist it round a small screw, and to tighten up the screw. The combination of conditions is unusually severe, for not only is the current of the alternating type, but there is a severe change of temperature at least twice daily.

Although perforated metal may appear to provide superior ventilation, as compared with sheet metal, the covers to the busbars, tails, and heater terminals, should be of the drip-proof type, readily removable, and be ventilated, and should also be provided with a well-designed cable or conduit entry.

At this point it may be well to mention that, in the earlier installations, rapid deterioration of the rubber insulation to the feeder cables occurred, owing to the excessive temperatures developed at the terminal connections, and in one or two installations the authors had the last 3 or 4 in. of the tube "de-loaded," i.e. the spiral resistance wires were stopped an inch or so short of the faceplate, and the straight wire brought through to the faceplate terminals. Improvements in the design of the terminals, the tails, the busbars, and the ventilation of the cover, have resulted in reduced temperatures, but cambric- and asbestos-insulated cables may still be considered preferable to vulcanized rubber, and the effect of coating the external surface of the faceplate with aluminium paint is worthy of trial.

Since, for various reasons, it is desirable to assemble the individual heaters in groups of 20 to 100 kW on a flat faceplate, and the faceplate has to be applied to the shell of a cylindrical vessel, it frequently becomes necessary to introduce a neck-piece or stand-pipe between the faceplate and the vessel. This neck-piece should be as short as possible, in order that the main convection stream, through the entire length of the heater, should experience the minimum interference, and also that the withdrawal space for the heaters may be reduced to the minimum.

The horizontal axis of the heater groups may be truly horizontal, but it is preferably inclined slightly upwards, in order to provide a drainage slope for any moisture that may be condensed within the tube, to vent the neck-piece, and to assist the water to flow freely from the neck-piece into the main body of the vessel. A sludge cock should be provided for each neck-piece, for the amount of sludge that accumulates in the vessels is really remarkable, considering that the same water is used for years and that it is never boiled.

(3) General Arrangement of Immersion Heater Plant.

The group or groups of 3-, 4-, or 5-kW immersion-heater units may either be located in the main storage

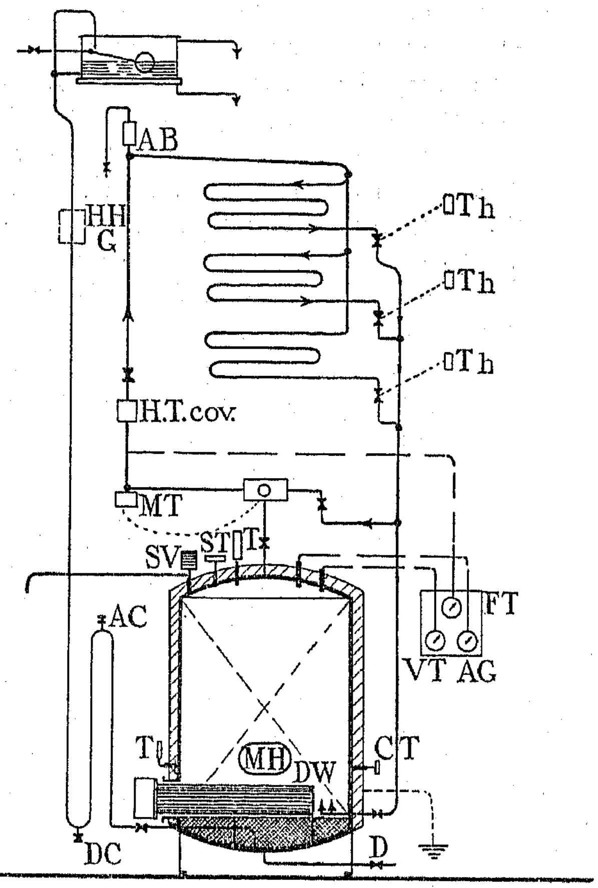


Fig. 12.—General arrangement of pipework to immersion-heater type thermal-storage plant.

Note.—If a pumped circulation is employed, an "up-flow" system may be used or, alternatively, a flow-reversing valve may be installed.

AB = air-release bottle and cock.
HHG = heat generator (if installed).
Th = room thermostats to local valves
H.T. cov. = high-temperature cut-off valve (prevents high-temperature water reaching radiating surface if mixing valve fails).
MT = thermostat to mixing valve.
SV = safety valve.
ST = safety thermostat.
T = thermometer.
FT = flow temperature.
VT = vessel temperature.
AG = altitude gauge.
CT = control thermostat.
MH = manhole.
D = drain.
AC = air cock.
DC = drain cock.
Double-hatched section shows dead-water space.

vessel, which may contain several thousands of gallons of water, or they may be inserted in a separate vessel containing a much smaller quantity of water, the smaller vessel or circulator being connected to the main storage vessel by means of the usual flow and return pipes, adequately valved to permit the smaller vessel to be isolated and emptied without affecting the main storage. In the earlier stages of development the latter arrangement was favoured, as failure of the resistance element

frequently necessitated the removal of the entire unit (element and containing tube), and this, in turn, necessitated the discharge of the water in the vessel containing the heaters. Separate heater vessels or circulators usually necessitate the allocation of additional space for the plant, and complications arise in connection with the circulation of the water between the circulator and the main storage vessel. To sink the circulator to a lower level than the main storage vessel (in order to provide a gravity circulation) frequently involves costly excavation and also introduces difficulties in connection with drainage. The alternative method of pumping the water between the circulator and the main storage vessel involves the allocation of additional floor space, makes the installation more costly, increases the operating expenses (cost of pumping and increased heat losses), and complicates the switchgear, since the pump must be interlocked with the immersion-heater circuit in such a manner that the heater cannot be switched in until the water is circulating, and failure of the water circulation must immediately switch off the current to the heaters.

Although it may possibly involve a slight increase in the capacity of the main storage vessel, it is generally considered that the design and construction of immersion heater units has now reached the stage where they form an extremely reliable piece of apparatus, and present-day practice therefore is to locate them in the main storage vessel.

The general arrangement of a typical plant, such as that installed at the Bankside Control Building, South-East England, for the Central Electricity Board, is shown in Fig. 12 and the only point calling for special comment is that of the supply of instruments. An altitude gauge is a desirable if not an essential item of equipment, to indicate the height of the water in the system without the necessity of inspecting the feed tank which is located at the highest point of the system.

Thermometers may be either of the dial or stem type, depending on the number and type installed, and also on the money available. The thermometer fitted to the top of the storage vessel is preferably of the dial and maximum-indicating type, so that a record is available of the highest temperature registered between successive inspections. It is also recommended that a mercury thermometer should be fitted immediately adjacent to each thermostat as a check on the operation of the thermostat in question.

(4) Classification of Electrode Heaters and the Conductivity of Water.

Electrode heaters, i.e. heaters in which the water itself carries the current and acts as the resistance, may be classified into the following main groups:—

(*a*) Low- and medium-voltage water heaters (up to 600 volts).

(*b*) High-voltage water heaters (600–11 000 volts).

(*c*) Low- and medium-voltage steam boilers (up to 600 volts).

(*d*) High-voltage steam boilers (600–11 000 volts).

Intimately connected with the design and operation of electrode heaters is the question of the conductivity of water at various temperatures within the normal working range, and it is proposed briefly to examine this item.

To those engineers who are familiar with the risk of severe or fatal electric shock at voltages of the order of 230–400, when in the vicinity of damp floors, water, etc., and who have not studied the subject of electrode water-heaters, it doubtless appears that it would be impossible to close the circuit of a 6 000-volt, 1 000-kW electrode water-heater or boiler without any appreciable movement being visible on an ammeter connected in one of the phase lines. Yet such occurrences are an established fact, the resistance of ordinary tap water being found to range from 1 200 to 12 000 ohms per cm per cm^2, the more normal range falling between the limits of 2 000 and 5 000 ohms per cm per cm^2.

According to data quoted by Pender,* the change of

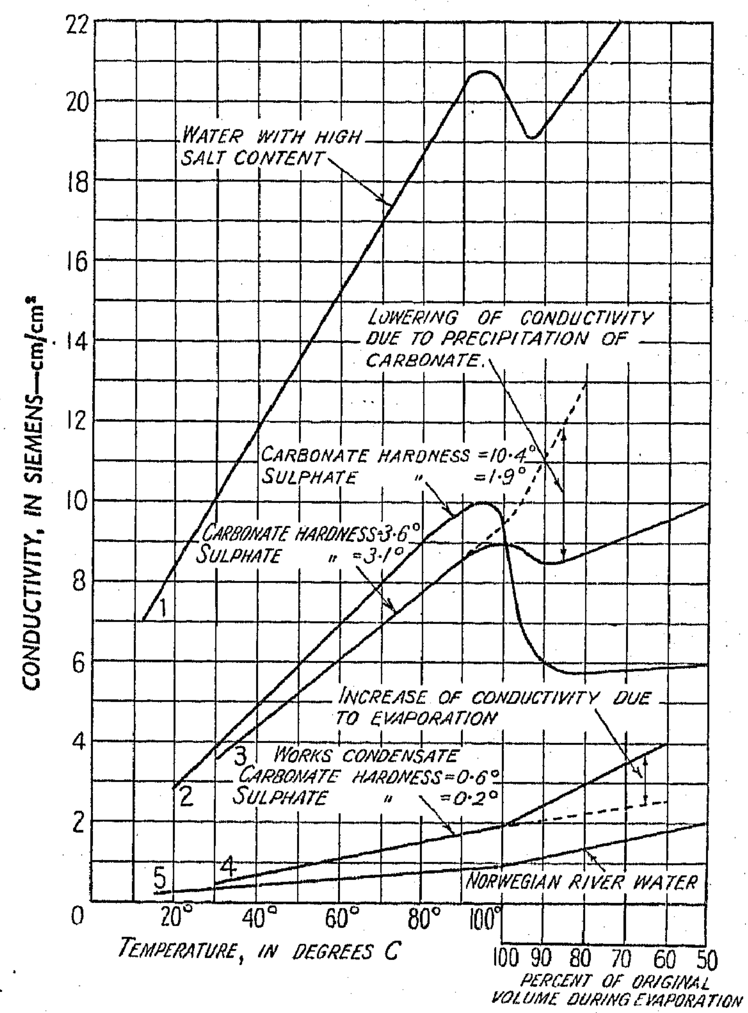


Fig. 13.—Variations in electrical conductivity of water with variations of temperature.

[Reproduced by the courtesy of Siemens-Schuckert (London), Ltd.]

resistance of such water with temperature between the limits of 0° C. and 100° C. may be represented to a fair degree of approximation by the formula

$$R_t = \frac{40R_{20}}{20 + t}$$

where R_{20} is the resistance at 20° C., and t is any temperature between 0° C. and 100° C. Thus, if the resistance at 20° C. is 3 500 ohms per cm per cm^2, then at 100° C. it will fall to 1 170 ohms per cm per cm^2, or to approximately one-third of its original value, so that the necessity for the employment of automatic load-controlling devices becomes obvious, i.e. devices which will hold the current approximately constant against a falling resistance with rise of temperature (see Fig. 13).

* See Bibliography, (6).

Salts available for the improvement of the conductivity of water include sulphates of zinc, copper, and sodium, the carbonate of sodium and the chlorides of sodium and ammonia, the most suitable being sodium carbonate or ordinary washing soda. According to data quoted by Pender, the results given in Table 4 are obtained with varying strengths of solution.

For a dilution less than 5 per cent, the resistivity is approximately inversely as the percentage of dissolved salt, i.e. a $2\frac{1}{2}$ per cent solution would have a resistivity of approximately $22 \times 5/2\frac{1}{2}$ or 44 ohms per cm per cm^2. It should be noted that a solution cannot have a resistivity greater than the water from which it is prepared.

Commercial electrode heaters are now designed for water having a resistivity of from 200 to 1 000 ohms per cm per cm^2, according to type and voltage, and it is therefore usually necessary to lower the resistance of the water, by the careful addition of the soda solution when the full working temperature of the whole of the water in the system has been attained, to a point at which the desired loading of the plant can be obtained.

TABLE 4.

Resistivity of Solutions of Sodium Carbonate. (Tests by Applequest and McKenny.)

Weight of dissolved salt expressed as a percentage of weight of the solution	5	10	15
Ohms per cm per cm^2 at 18° C.	22	14·2	12
Temperature coefficient at 28° C.	− 0·025	− 0·027	− 0·029

(5) RATING OF ELECTRODE WATER-HEATERS.

The large variation in the resistivity of water between the temperature limits of 50° F. and 300° F. renders it possible to allocate only a nominal rating to any particular size of equipment. If, for example, a heater having a mean average rating of 750 kW throughout the run is required (such rating having been arrived at by reference to the total heat requirements of the building, the hours during which the supply is available, and similar considerations) it would be inadvisable to specify that the output of the apparatus must necessarily be 750 kW throughout the temperature range, for if it is designed to develop a maximum output of 750 kW at, say, 100° F., it will be capable of an output of nearly double this value at 300° F. Conversely, if the apparatus is designed for an output of 750 kW at the maximum temperature of 300° F., the output at 100° F. will be so low as to render the rise of temperature such a slow process that the full quantity of heat required cannot be obtained from it during the period in which electricity is available.

An electrode heater having a nominal rating of 750 kW which has been designed to operate between the temperature limits of 100° F. and 300° F. would actually give an output of approximately 450 kW at the lower temperature limit, and of 1 000 kW at the upper limit. A performance of this character would be quite satisfactory for the purpose from the point of view of heat supply, provided the total heat is delivered in the scheduled time, but it tends to make the switchgear costly.

An alternative method employed by the authors is to provide a bypass water circuit, controlled by an electrically operated valve, and arranged in a manner such that, in the initial stages of the run, the heat developed is exclusively employed in warming up the water contained in the electrode heater and local pipework. When this water attains the predetermined temperature corresponding to the rated loading of the electrode heater, the electrically controlled valve is gradually opened and sufficient cold water is admitted to the circuit from the storage vessel to maintain the load, the process of mixing being thermostatically controlled. Since the quantity of water contained in the heater is usually small in relation to the electrical loading and to the total water in the system, the temperature-rise of the water and the rise of the load to rated output is comparatively rapid, and, from this point, water may be discharged to the system at a constant temperature.

(6) DETAILS RELATING TO ELECTRODE HEATERS.

Electrode heater vessels, with possibly one exception, are of the vertical type, whether utilized for the generation of steam or for the heating of water. For the steam boiler, the majority of designers consider that load control may be cheaply and effectively provided by raising and lowering the water-level in the vessel, and it is therefore convenient to suspend the electrodes from the upper part of the vessel so that when the water is allowed to drain out the load falls to zero. Conversely, when an increase of load is required, more water is pumped into the vessel, thereby immersing a greater depth of electrode.

In the water form of the electrode heater and also in certain designs of steam boilers, it is convenient permanently to locate the electrodes in the lower part of the vessel, and to provide for the control of the load by suspending movable electrode shields of tubular form over the electrodes. Suitable shield guides are provided within the vessel, and an operating rod passes through a gland located in the shell of the vessel. The position of the shields in relation to the electrodes, and hence the path of the current and its resistance value, may be adjusted by raising or lowering the shields, either by means of an hydraulic piston and cylinder controlled by solenoid valves or by means of a reversible motor and gearing.

An alternative form of control that has been developed depends upon the local generation of steam to force the level of the water down in the immediate vicinity of the electrodes, while at the same time retaining all the best features of the electrode water-heater.

The remaining fundamental departure from standard practice known to the authors is the development of the horizontal vessel equipped with a form of electrodes very similar in general design to the well-known variable con-

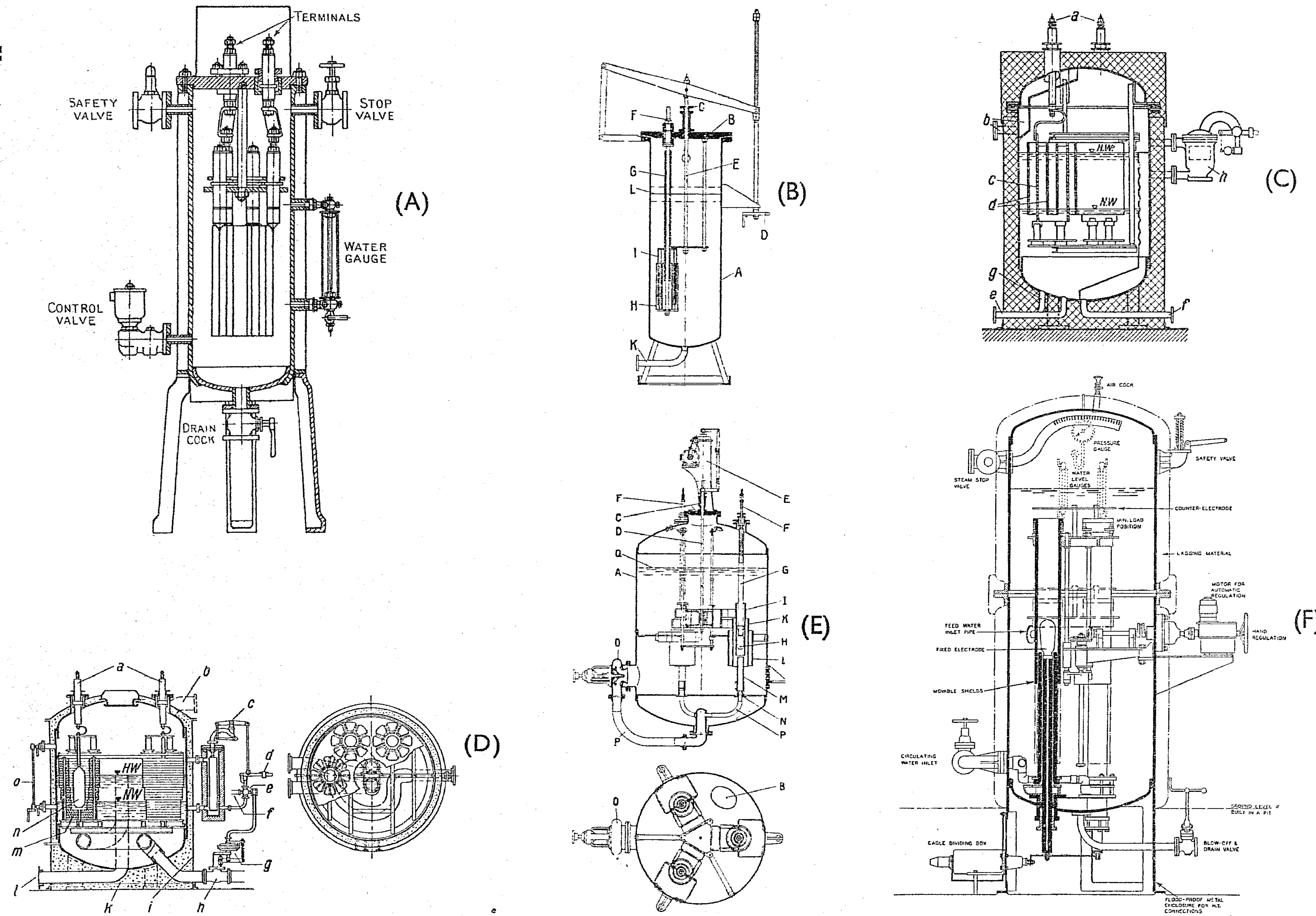


FIG. 14.—Typical Electrode Steam Boilers.

LOW- AND MEDIUM-VOLTAGE.—(A). Bastian & Allen Ltd. (Load control by adjustment of water-level by solenoid control valve.) (B). Sulzer Bros. (London) Ltd. (Load control by adjustment of counter-electrodes I running on the insulated tubes G and operated by the spindle E.) (C). Siemens-Schuckert (Great Britain) Ltd. (Load control by adjustment of water-level.)
HIGH-VOLTAGE.—(D). Siemens-Schuckert (Great Britain) Ltd. (Load control by adjustment of water-level; *h* feed valve, *l* blow-down, *b* steam pipe.) (E). Sulzer Bros. (London) Ltd., 6 000 kW. (Load control by adjustment of movable telescopic insulating shields I and K, by motor E; water circulated by pump O.) (F). A. Reyrolle & Co. Ltd. (Load control by adjustment of movable insulating shields and counter-electrodes.)

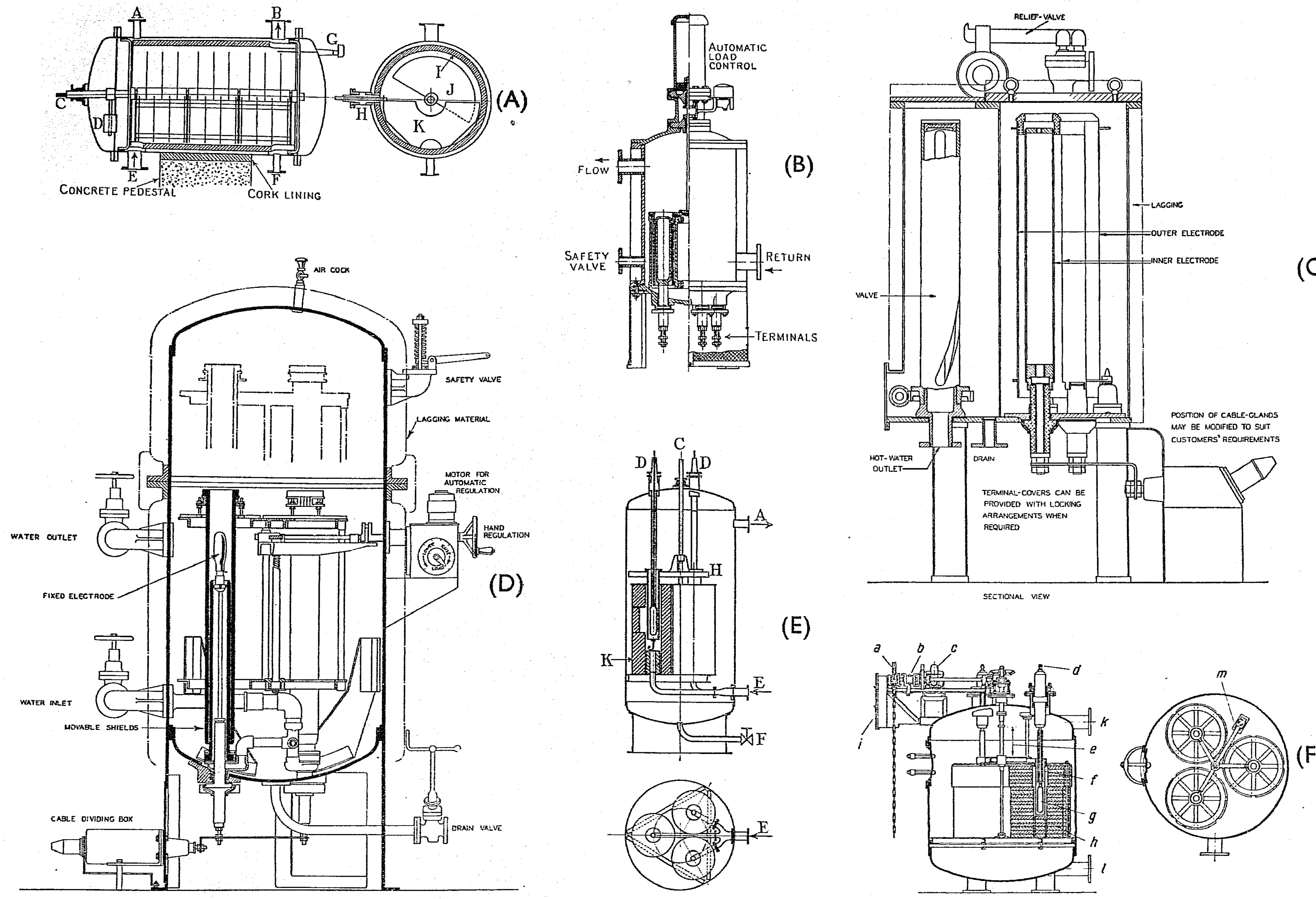


FIG. 15.—Typical Electrode Water Heaters.

LOW- and MEDIUM-VOLTAGE.—(A). General Electric Co. Ltd. (Load control by adjustment of moving electrode vane J, carried on spindle C, counterweighted by D, in relation to the fixed electrodes K; terminal bushings at H, insulating liner I, water inlet E and outlet B, safety valve A, safety thermostat G.) (B). Bastian & Allen Ltd. (Load control by adjustment of electrode shields by piston moving in the hydraulic control cylinder located on the top of the shell; movement of piston controlled by solenoid valves relieving water pressure above or below piston as required.) (C). A. Reyrolle & Co. Ltd. (Load control by adjustment of water-level by formation of steam bubble in concentric valve tube forming water outlet.)

HIGH-VOLTAGE.—(D). A. Reyrolle & Co. Ltd. (Load control by adjustment of the height of the outer electrode.) (E). General Electric Co. Ltd. (Load control by adjustment of the height of the electrode shields carried on the support H and the spindle C.) (F). Siemens-Schuckert (Great Britain) Ltd. (Load control by adjustment of electrode shields *f* through the height *e*.)

denser associated with wireless receiving equipment. In this type control of the load is achieved by varying the relation of the fixed and moving vanes of the electrode system, the vessel being lined with an insulating material.

Electrodes of silicon iron are found to give satisfactory service and have a life of several years.

Although in the electrode form of water heater the water is never evaporated, yet it is raised to high temperatures during each daily cycle, and there is a comparatively large volume of water available to deposit scale in the vicinity of the electrodes. Care must therefore be exercised to select heaters that are provided with ample clearances between metal operating at any substantial difference of potential, since the electrical conductivity of even small " bridges " of saturated scale is somewhat remarkable.

Fittings and mountings follow standard practice, and usually include the following:—

(*a*) Water inlet and stop valve.

(*b*) Water outlet and stop valve.

(*c*) Weighted or spring-loaded safety valve.*

(*d*) Water or altitude gauge, preferable of the dial type.

(*e*) Thermostat pocket, with emergency thermostat of the hand-resetting type.

(*f*) Thermometer pocket, with thermometer of the mercury-tube type so fixed that it may be used to check the operating temperature of the thermostat.

(*g*) Air valve, to enable the vessel to be filled and emptied when valved off from the pipe work.

(*h*) Drain valve.

Electrode water-heaters and steam boilers of the low- or medium-voltage type—up to 600 volts—can now be obtained in capacities varying from 25 to 1 000 kW, but considerations of cost will usually limit the use of water heaters to loadings of between 200 and 700 kW, the actual line of demarcation being somewhat difficult to determine. Below the 200-kW line the immersion heater equipment will usually be found to be the better commercial proposition for water heating, and above the 600- or 700-kW line the advantage most frequently lies with the high-voltage electrode heater, as it enables the transformer to be dispensed with and the transformer losses to be eliminated from the estimates of running costs.

The largest cable that can conveniently be laid in the streets is normally regarded as the 4-core, 0·5-sq. in., the maximum loading being approximately 520 amperes, which corresponds to 330 kW at 400 volts and unity power factor. If two such cables are looped into a building, then the total load available would be 660 kW, but a load of this magnitude would probably prove inconveniently large to supply from the medium-voltage network, and it would be more usual to lay in a high-voltage service and provide a local transformer for the general load of the building—lighting, lifts, hot-water supply, etc.

The advantages of space occupied naturally lie with the low- and medium-voltage electrode heaters. One well-known make, which is rated to develop 500 kW or 1·7 million B.Th.U. at 400 volts, has an overall diameter of 3 ft. and an overall height of 8 ft., the maximum headroom required to withdraw the electrodes being limited to 9 ft. 6 in. Typical dimensions of 6 600-volt heaters are shown in Table 5.

* The National Boiler and General Insurance Co., Ltd., have approved the following sizes: 30 kW, ½ in.; 150 kW, ¾ in.; 250 kW, 1 in.; 375 kW, 1¼ in.; 500 kW, 1½ in.

At 11 000 volts, all sizes of this make up to 3 000 kW are 10 ft. 6 in. high and require a height of 13 ft. 6 in. to enable the electrodes to be withdrawn, the diameter being 3 ft. 6 in.

Initial cost and reliability in service have an important bearing on the size and number of units to be installed in any given building, but it must be conceded that the electrode water-heater is an extremely robust and simple piece of apparatus. Access is readily obtained to the interior of the shell, and the replacement of such parts as are liable to failure is a comparatively simple matter and one that could normally be attended to during the " off " period of supply. The provision of spare heaters or duplication of the plant therefore is seldom justified on the score of maintenance of essential services, although it may be necessary to subdivide the plant for reasons of convenient accommodation in the space available. On the score of economy during periods of light load, subdivision is rarely justified, for the loss of heat from a well-lagged shell is extremely small, the heat generation has an efficiency of 100 per cent, and standard load control is now available between the limits of 30 and 120 per cent.

TABLE 5.

Leading Dimensions of Typical 6 600-*Volt*, 3-*Phase Electrode Water-Heaters.*

Rated capacity	Overall height	Maximum height required for withdrawal of the electrodes	Diameter
kW	ft. in.	ft. in.	ft. in.
500	10 6	13 6	3 6
1 000	10 6	13 6	3 6
1 500	13 6	16 6	4 6
2 000	13 6	16 6	4 6
3 000	13 6	16 6	4 6

In all cases connected with the installation of electrode heater plant, it should be noted that the prior consent of the Electricity Commissioners is required, since the shell forms the neutral of a 3-phase system, and the earthing of the shell at each installation automatically converts the distribution system into a multiple-earthed neutral system, which is prohibited in the Commissioners' Regulations.

(7) General Arrangement of Electrode Heater Plant.

The general arrangement of electrode heater plant is shown in Fig. 16, and a very brief examination will indicate that it follows very closely the general scheme of the immersion heater plant already described and shown in Fig. 12. The principal alteration lies in the employment of the independent heater and the addition of the primary pump, which is almost invariably provided

for the purpose of circulating the water through the heater. In the case of the electrode plant the safety thermostat is located in the heater, but the control thermostat remains in the main storage vessel, as in the case of the immersion heater plant.

So far as can be seen at present, it would appear to be impracticable to locate the electrode heater in the main storage vessel, both on account of accessibility for repairs without discharging large quantities of hot water, and also for reasons of space occupied and circulation within the vessel.

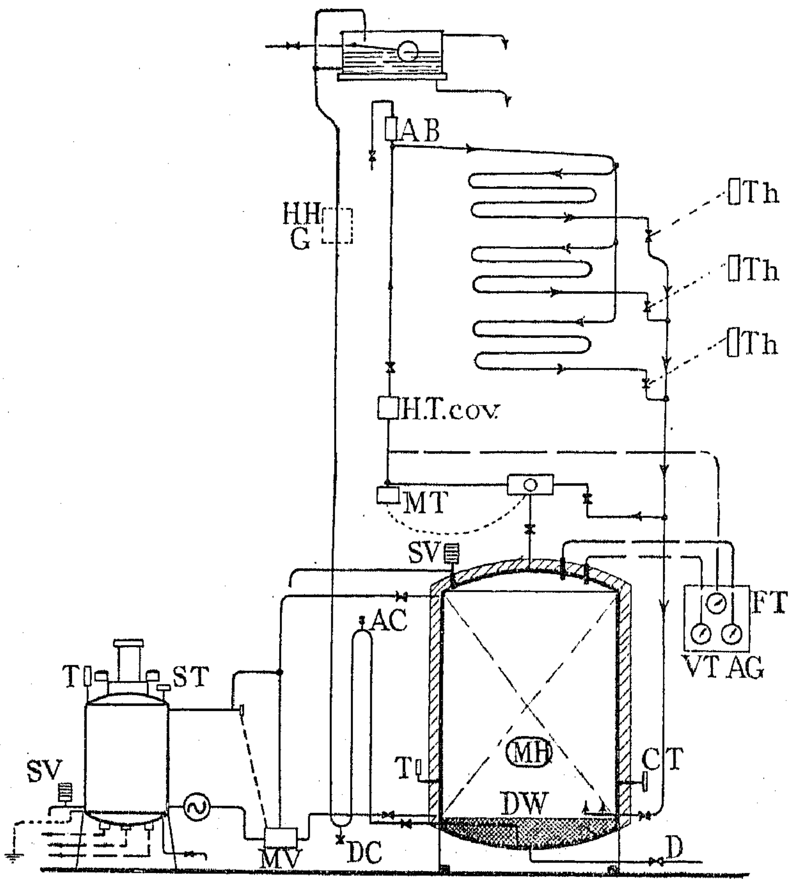


FIG. 16.—General arrangement of pipework to electrode water-heater plant.

NOTE.—If a pumped circulation is employed, an "up-flow" system may be used, or, alternatively, a flow-reversing valve may be installed when the system is required to run on gravity during the night.

AB = air-release bottle and cock.
HHG = heat "generator" (if installed).
Th = room thermostats to local valves.
H.T. cov. = high-temperature cut-out valve (prevents high-temperature water reaching the radiating surface if the mixing valve fails).
MT = thermostat to mixing valve.
SV = safety valve.
FT = flow temperature.
VT = vessel temperature.
AG = altitude gauge.
CT = control thermostat.
D = drain.
MH = manhole.
DW = dead-water space.
T = thermometer.
MV = mixing valve.
~ = circulating pump.
ST = safety thermostat.

Section 2. DETAILS RELATING TO THE ELECTRICAL CONTROL OF IMMERSION AND ELECTRODE HEATER EQUIPMENT.

(1) TEMPERATURE CONTROL OF THE LOAD.

Although the modern thermostat is an extraordinarily reliable item of equipment, it has now become standard practice on all large heating plants to provide two instruments connected in series, the one (termed the "control" thermostat) designed to operate at the normal maximum temperature, while the other (termed the "emergency" or "safety" thermostat) is set several degrees higher.

Practical experience has shown that it is not possible regularly to work right up to the boiling-point of the water, and a margin of 20 deg. F. is therefore allowed between the boiling-point and the setting of the "control" thermostat during spells of extreme weather, but during spells of normal winter outdoor temperatures this setting can, with advantage, be lowered so that the plant is only occasionally submitted to the strains of extreme temperature cycles. The "safety" thermostat is normally set about 10 deg. F. below the boiling point.

Very fortunately, the process of "ageing" of thermostats appears to be in the direction of lowering the operating point, i.e. in the direction of safety, rather than in the direction of danger, so that after the first or second heating season it is not an uncommon experience to find that it is necessary to set the thermostat "up" slightly, in order to maintain the desired operating temperature.

Thermostats of the hand re-setting type, fitted with "back" contacts, are now available, and these should be employed for the "safety" position, so that the plant cannot be automatically put back into commission until the cause of the excess temperature has been investigated and dealt with; also the fact that the plant is out of commission can be signalled by means of a lamp or other indicating device, connected to the "back" contact.

An important point connected with thermostatic control of large installations is the reliability of the cable connections when they are more or less continuously submitted to the temperatures prevailing in the vicinity of the heaters and the storage vessels. Stand-pipes or extension tubes should be provided in the walls of the vessel to raise the thermostat head clear of the thick heat-insulating covering to the vessel, so that it may operate at a temperature as low as the situation permits, and consideration should also be given to types of insulation other than fully or partly vulcanized rubber, such as cambric associated with asbestos or other heat-resisting material.

Care must be exercised in selecting the position of the thermostats, for if they are placed too high in the vessel it will fill up with a very substantial quantity of cool water before they again close the circuit, and the "off" period may be commenced with a vessel half full of cold water. Conversely, if they are placed too low the plant may start up and shut down at very frequent intervals after the first heat run of the night has been completed. Again, in vessels in which the circulation is sluggish during the heat run, the temperature at the top of the vessel may be substantially higher than at the thermostat position, and if the margin between the thermostat setting and the boiling point is small the water may boil before the thermostat opens the circuit.

(2) TIME CONTROL OF THE LOAD.

The following four methods of controlling the time incidence of these off-peak loads appear to be possible:—

(a) Time switching by means of electrically wound or

synchronous-motor-driven clocks having a spring reserve-drive located on the consumer's premises.

(*b*) Pilot-cable switching of control relays or contactors on the plant from distant control centres or manually operated substations.

(*c*) Ripple switching by the utilization of relays tuned to respond to frequencies of the order of 750–1 500 cycles per sec., the ripple being superimposed on the general distribution system from a central point, and the area affected being limited by the introduction of chokes at suitable points in the distribution network.

(*d*) Impulse switching by the use of relays designed to operate in response to impulses dialled either manually or automatically from a central control station.

At the present time, the electrically wound time switch is almost universally employed, but although it is extraordinarily reliable it is not entirely free from the risk of breakdown. Synchronous clocks offer the very definite advantage of accurate time-keeping, coupled with a remarkable degree of reliability, but the effect of an interruption of supply is so pregnant with unpleasant possibilities, in the direction of disorganizing the switching time-table in a well-developed area, that their general adoption has been materially retarded.

Pilot-cable switching has been seriously considered in several areas of supply where the rise and fall of the load is somewhat erratic and where the engineers have desired to continue the supply for the maximum number of hours per day, in order to limit the cost of the installation to the minimum. While such a system should be practicable in a new area where the cables have still to be laid, investigations of cost in fully cabled areas almost invariably result in the proposal being dropped in favour of time switches.

Ripple switching appears to the authors to offer distinct possibilities, and very favourable reports have been received in regard to the trial installations that have been in operation in Paris for the purpose of switching-over the dials of 3-rate meters.

Impulse switching over the Post Office lines or over the supply cables offers distinct possibilities, and especially is this so in view of the remarkable development that has recently taken place in connection with the control arrangements installed by the Central Electricity Board at Bankside and at other centres.

(3) Automatic Overcurrent Protection for Groups of Immersion Heaters.

The problem of overcurrent protection of groups of immersion heaters is a combination of technical, commercial, and practical considerations. The individual units are usually designed for a loading of either 3, 4, or 5 kW, so that the parts are of relatively light construction, and this indicates that the current per circuit should be so limited that a fault will not seriously damage the equipment. To protect them individually involves a mass of cable connections or the location of a large number of small-capacity overcurrent protective devices in the immediate vicinity of the heaters, where they will be exposed to excessive temperatures, and, while the cost will be relatively high, the multiplication of small parts in unsuitable surroundings will tend to lower rather than to maintain or to raise the safety factor. Therefore the possibility of group protection has to be considered, with the object of maintaining the safety factor and limiting the cost to a reasonable figure.

To enable the decision to be made regarding the minimum protection to be provided to ensure reasonable safety, an analysis of the possible faults follows:—

(*a*) The burning-through and subsequent open-circuiting of an element without damage to itself or its surroundings. It would be useful for this fault and the corresponding loss of heating capacity to be indicated, but no disturbance to the healthy units should automatically follow.

(*b*) Short-circuit between the phase and neutral wires of the element. This may take the form of a dead short-circuit if it occurs on the terminal block, but if it occurs some distance along the element the fault current will be limited by the amount of the resistance in circuit, and the overcurrent may or may not be sufficient to operate the safety device, depending on the closeness of the setting. The fault may therefore persist until overheating and failure occurs.

(*c*) An earth fault may develop between the phase line and the metal-containing tube, and this may be either of the " dead " or the " high resistance " variety, depending on the point where it occurs. If the latter, overheating of the element wire will take place until a hot spot burns through or water penetrates a puncture in the tube.

These are the possible faults, and the protective gear, which must be relatively simple, reliable, and inexpensive, to compete with cast-iron boilers, should aim at the prevention of vicious or sustained arcs within the metal tubes, since puncture of the tubes would result in the loss of considerable volumes of water which may do serious damage should the fault develop during the early part of the night or the week-end, when the building is unattended.

Unbalanced-phase protection does not appear to serve the purpose, for not only may this cut out when there is no real necessity, but it introduces unnecessary difficulties into the design of the heater groups in the direction of initial balancing of the load on the three phases, and materially adds to the cost of the installation. A 55-kW load calls for three groups of $18\frac{1}{3}$ kW, or possibly 19 or 20 kW, and this may be met either by providing 4 tubes of 5 kW, 6 tubes of $3\frac{1}{6}$ kW, or 4 tubes of $4\frac{3}{4}$ kW per phase, all equally unsatisfactory.

Experience shows that there are thousands of immersion heaters of 2 kW, 3 kW, and 4 kW capacity in daily use with satisfactory results, and it is the almost universal practice to protect them against overcurrent by fuses rated to carry approximately 15 amperes and to blow at approximately 30 amperes. It therefore follows that if automatic overcurrent protection can be designed to operate with an excess load of 15 amperes per phase, then equally satisfactory results should be obtained from grouped heaters if they are protected to that extent. Table 6 shows the ratio of this value of 15 amperes to the phase current and to the total kW on a balanced 3-phase circuit.

Inquiries show that manufacturers encounter little or no difficulty in providing air-break circuit breakers designed to operate with every degree of stability, and to

trip with entire reliability when set to 20 per cent overload (corresponding to grouping of 50–55 kW), and that now that the demands have been made, limits as close as 12½ and even 10 per cent can be obtained, corresponding to groupings as high as 90 to 100 kW.

The remaining line of attack to be investigated is the utilization of the earth-return current from an earth fault to trip the main contactors. This method introduces several practical difficulties, as the storage vessel is necessarily connected to the general system of pipework by several valves, and, although the metal-to-metal contact can be eliminated by the employment of suitable packing material to the joints, the small separation of the adjoining sections of metal provides an extremely short path for the current. The cross-sectional area of the water contained in the pipes is also substantial, and when the water is hot the resistance across the joint may be of the order of 0·25 ohm. Short lengths of insulated pipe might be introduced into each connection if suitable material is available which may be safely used with superheated water under a static head of the order of 100 ft. A further point that requires consideration with this type of gear is that it must not operate with "foreign earths," i.e. fault currents from other sections of the electrical installation that may find the shortest way to earth via the hot-water pipes, the storage vessel, and the main earthing connection attached thereto.

In view of the difficulties and the cost of the method, this form of protection has not been further investigated.

(4) Electrical Control Gear.

From the point of view of voltage regulation, the automatic opening and closing of relatively heavily-loaded heating circuits under time-switch and thermostatic control is undesirable, but, conversely, from the point of view of the consumer, insistence on the provision of complicated switchgear and masses of cables, relays, etc., involves heavy initial expense and probably increased maintenance charges (see Fig. 17).

In the case of the electrode heater, continuous smooth adjustment of the output is possible between the limits of 30 and 120 per cent, either by hand or automatic control, and in many cases this control gear incorporates means for automatically returning the load control gear to the minimum-load position before switching off. Again, the variation in the conductivity of the water with the temperature automatically ensures a comparatively low-load value when switching in for the first time each evening, but this reduction will not be so effective if the plant switches in again during the night, after completing an initial run, due to the fact that the water will be at a higher temperature as the plant will be operating on the differential of the thermostat and not on the time switch.

In the case of an immersion-heater installation exceeding a capacity of 30–40 kW, the load will almost invariably be divided between two or more groups, and these may be switched either as individual groups or as a single paralleled group, the former method possessing the advantage of reliability due to subdivision, while the latter has the merit of low initial cost. Where the extra cost of load switching by steps is regarded as essential to prevent undue disturbance to the voltage regulation of the distribution system, one group will have no time-lag device and will respond directly to the operation of the time switch. The remaining groups will each be fitted with its own time-lag device, each adjusted for a slightly different interval of time, and for opening the circuits the differentials of the thermostats may be relied upon *not* to switch off the several circuits simultaneously. If the storage vessel and the heaters are of adequate capacity, the time switch will not usually be called upon to open the circuit, except possibly on a boosting charge.

The operations involved in the control of an electrode water-heater may be briefly described as follows:—

(*a*) The time switch closes at a predetermined hour each day.

(*b*) If heat is required, the control thermostats have completed the closing of the control circuit, so that the primary pump starts up and circulates water through the electrode water-heater.

(*c*) The closing of the pump contactor should return the electrode shields to the minimum-load position (if that has not already been done before shutting down), and a water-flow contact will complete the control circuit of the main switch controlling the supply, thereby closing the switch.

(*d*) An instrument transformer having its primary associated with one phase of the main supply to the electrodes closes a relay and the electrode shields will be moved into the maximum-load position, by the action of either a reversible motor or a solenoid-controlled water valve, and they remain in that position until the pre-

Table 6.

Ratio of Permissible Overload Current of 15 *Amperes to the Phase Current and to the Total Load on a* 3-*Phase Circuit.*

3-phase kW	30	35	40	45	50	55	60	65	70	80	90	100
Phase amperes at 230 volts	43	50	58	65	72	79	86	94	102	115	129	144
$\frac{15 \text{ amps.} \times 100}{\text{Phase amps.}}$	35	30	26	23	21	19	17·4	15·9	14·7	13	12·8	10·4

Note.—Inspection of Table 6 clearly indicates that if the automatic overcurrent trips are set to operate below 17·4 per cent overload, on a 3-phase 60-kW group, the degree of protection afforded is closer than that provided by a 15-ampere fuse (blowing at 30 amperes) protecting a single-phase 15-ampere immersion unit.

determined load is attained. This maximum-load position is not necessarily the maximum rated output of the heater, as it may be desired to spread the load over the available period of supply. Provision is therefore generally made for an adjustment of the maximum operating load between the limits of 25 and 120 per cent by means of tappings on the instrument transformer, by adjustable cores or resistances, or otherwise.

(*e*) Immediately the point of maximum operating load is attained, any tendency to overload is checked by a reversal of the relay, when the electrode shields will be moved to the desired position.

(*f*) When the thermostat or time switch opens, the load control reverses to the minimum-load position, and the main and pump contactors open.

(*g*) In the event of a heavy overload or short-circuit occurring, the main electrode switch opens instantaneously and remains open until the cause has been investigated and the trips have been re-set by hand.

(*h*) In the event of the load current becoming unbalanced between the phases, the unbalanced-phase protective gear opens the main switch to the electrodes.

The next point for consideration is the control of the main 400-volt supply, either to the immersion-heater groups or to the electrodes. Had this paper been written two or three years ago it is probable that the authors would have recommended the use of oil switches for all current values exceeding 100 or 150 amperes. The air-break contactor has, however, now reached the stage where experience shows that, if correctly designed, it is entirely reliable for the control of loads of the order of 500–600 amperes, and at least one manufacturer is now offering it for currents of 1 200 amperes. It is true that failure has been experienced with flash-overs between phases, with "freezing" of the arc tips, with excessive hum from the hold-in coil, and also with the excessive noise of the "closing slap," but effective barriers and blow-out coils deal satisfactorily with arcs on all normal circuits, and improved design, with or without the use of metal rectifiers to operate the closing coil, renders the contactors practically silent in service and reasonably silent in closing.

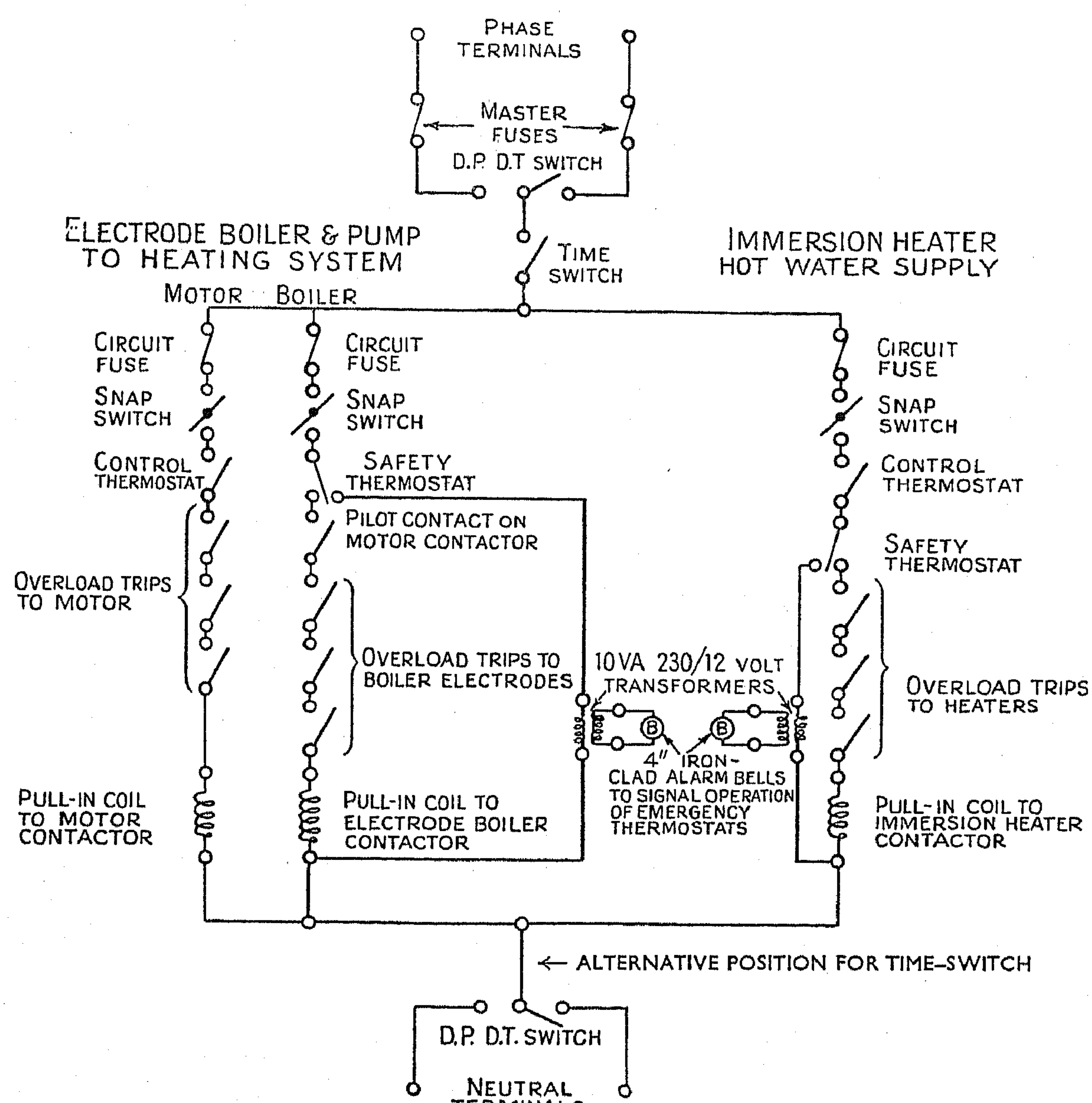


FIG. 17.—Basic control circuit to medium-voltage electrode water-heater to heating installation and to immersion-heater group to domestic hot-water supply installation.

The desirability or otherwise of associating the automatic overcurrent devices with the contactors is a point that requires careful consideration, and especially is this so when the contactors are connected to heavy-duty systems or to large transformers by very short lengths of heavy cable. Additional security can be obtained by interposing chokes or heavy-duty cartridge fuses, but the authors are of the opinion that fuses should not be

used on electrode heater circuits in view of the risk of "two-phasing" and the development of heavy earth currents following the failure of a single fuse. A further alternative is to time-lag the overcurrent trips and to rely on a control switch nearer the source of supply for the full rupturing capacity required, but this proposal would appear to negative the use of the overcurrent trips on the contactor panel, although, where the main supply is subdivided to feed two or more groups of immersion heaters or two or more electrode heaters, it may become necessary to combine the overcurrent devices with the contactors, in order to provide protection for the individual groups or heaters.

In any case it would appear very desirable to control, as a unit, contactor gear, whether of the air-break or of the oil-immersed, motor- or solenoid-operated type, by means of a separate hand-operated switch for use in an emergency, and also for the purpose of complete isolation when the plant is being cleaned and overhauled. This isolating switch may be of the oil-break type, and would normally be fitted with automatic overcurrent trips for the protection of the cable between the supply and the contactor gear.

The combination of isolating switches of the slow-break type with the contactor gear, depending for their operation on the opening of the load on the contactor gear, and interlocked with the access doors, is not favoured by the authors, as they consider that additional and unnecessary features and cost are thereby introduced into the equipment, without the definite advantages of complete isolation and positive interruption of the full-load current by hand, or automatically in emergency, if and when required.

For the control of the 6 000- and 11 000-volt supply to the electrodes on high-voltage installations, motor- or solenoid-operated switches of standard types are employed and call for no special comment.

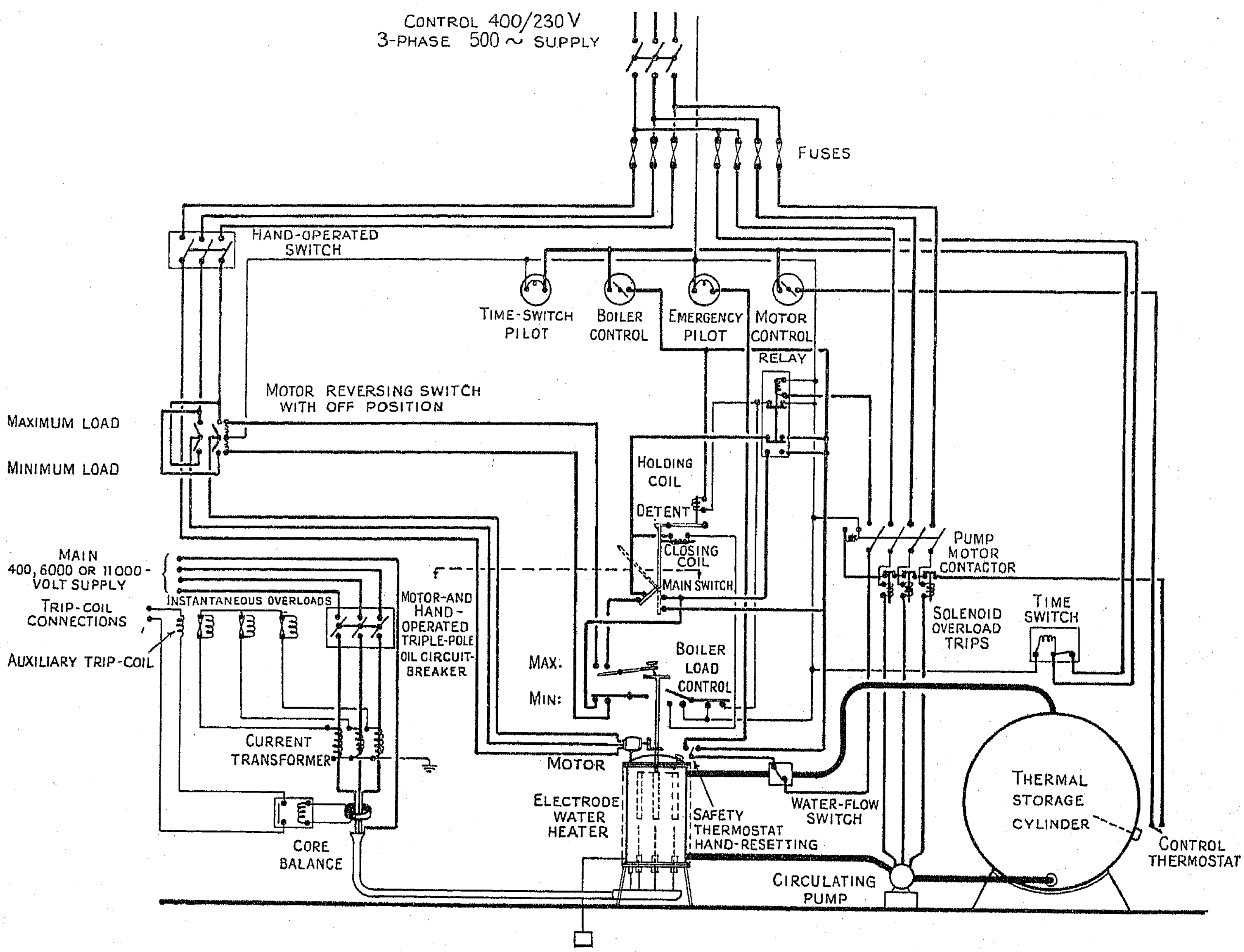


FIG. 18.—Basic diagram of connections to medium- and high-voltage electrode water-heater installation.

Money spent on ammeters is almost invariably well spent, and certainly one ammeter per circuit would appear to be an indispensable item of equipment of every control panel. The question of equipping the remaining two phases with ammeters is largely one of economics, the desirability being an accepted fact for an immersion-heater installation although possibly not quite so definitely established for an electrode-heater installation and also for the circuit of its associated circulating pump.

It is desirable, if not essential, to bring the neutral conductor into the controller, and to supply the control circuit between phase and neutral, as the majority of thermostats, water-flow contacts, etc., are designed for

230-volt circuits and may not be suitable for 400-volt circuits.

It should be unnecessary to mention that all thermostat, time switch, and other control circuits should be fused at the point where the circuit is connected to the heavy-current bars, although one well-known manufacturer recently submitted diagrams showing the 3-ampere switches, thermostats, and several hundred feet of 3/·029 cable connected solidly to the 500-ampere circuit.

It is recommended that the pull-in coil of the contactors should be connected at the neutral end of the control circuit, rather than at the phase end, so that an earth fault on any of the thermostat or other controls or their connecting cables will blow the fuses and leave the pull-in coil out of circuit. The alternative method of connecting the pull-in coil to the phase conductor, followed by the thermostats and time switches, is unsound, for, in the event of a fault developing, a high-resistance coil is interposed between phase and earth, and the contactor may close despite the fact that the thermostats may have opened when the predetermined temperature has been reached.

For the operation of contactors exceeding 100 amperes capacity, it is recommended that the closing coil should be operated through a rectifier in order to eliminate the risk of excessive hum, to minimize the closing "slap," and to ensure that the "safety" thermostats can handle the total control current.

It should be noted that in the 10th edition of the I.E.E. "Regulations for the Electrical Equipment of Buildings," unbalanced-phase protective gear is required for electrode water-heaters and boilers.

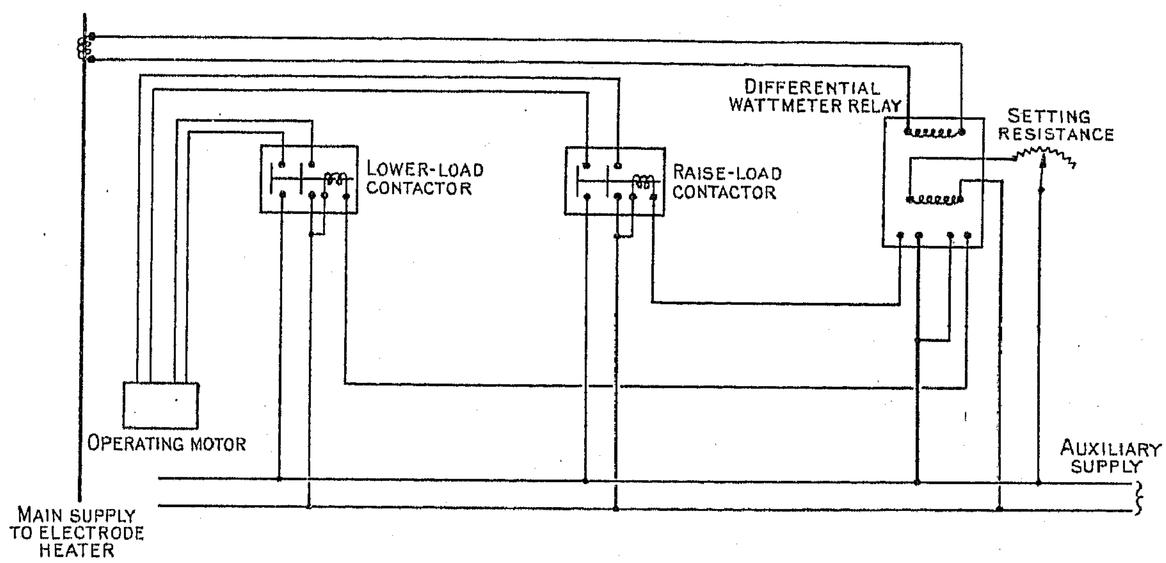


FIG. 19.—Differential-wattmeter method of controlling the load.
(Reproduced by the courtesy of A. Reyrolle & Co. Ltd.)

TABLE 7.

Current in A.C. and D.C. Contactor Coils at 230 Volts.

Contactor rating	Momentary pull-in current	Maintained holding-in current
amps.	amps.	amps.
30	0·7 (a.c.)	0·12 (a.c.)
75	1·75 (a.c.)	0·17 (a.c.)
150	4·50 (a.c.)	0·5 (a.c.)
250	6·50 (a.c.)	0·7 (a.c.)
350	15 (a.c.)	1·5 (a.c.)
350	1·6 (d.c.)	0·64 (d.c.)
500	1·6 (d.c.)	0·64 (d.c.)

(5) CABLE CONNECTIONS.

The standard types of vulcanized-rubber and paper-insulated cables recognized by the I.E.E. Regulations do not prove entirely satisfactory for the connections to the heaters and to the thermostats, owing to the relatively high temperatures that prevail in the vicinity of the terminals, and a definite lead from the Institution would be welcomed in regard to this detail.

Various types of insulation have been reviewed and tested, and good results are now being obtained with a combination of cambric and a form of asbestos insulation, where the situation is reasonably dry. Single-core, lead-sheathed cables are now being employed for the connection of a pair of 1 000-kW 5 000-volt 3-phase electrode water-heaters.

It is appropriate to observe at this juncture that thermal-storage equipment is frequently installed below drain-level, and that water must be lifted from a sump which is of limited capacity. Under these circumstances it is prudent to contemplate the possibility of the flooding of the plant room to a depth of 12 or 18 in. and to employ materials and to arrange the details accordingly.

Bonding to earth of the shell and all exposed metal liable to become alive is effected by the standard 1 in. × $\frac{1}{8}$ in. copper tape.

Section 3. DETAILS RELATING TO WATER-STORAGE VESSELS AND PIPEWORK.

(1) TEMPERATURE CYCLE AND WATER STORAGE REQUIRED.

The main factors that determine the quantity of water and the storage capacity required are as follows:—

(*a*) The hourly heat requirements of the building and

also the heat required for the hot-water supply and ventilating systems (if either of the latter are installed).

(*b*) The temperature range through which the storage water may be operated. If T_1 represents the maximum temperature to which the water may be safely raised during each cycle without risk of the formation of steam, and T_2 represents the minimum useful temperature at which the water may be supplied to the distributing system, then $(T_1 - T_2)$ is the temperature range or daily cycle.

(*c*) The number of hours per day during which electrical energy can be made available for heating the water. (The hours need not necessarily be consecutive.)

(*d*) The heat not effectively employed (i.e. lost by radiation from the vessel, pumps, valves, pipework, etc.).

Clearly, for minimum storage capacity, both the temperature range and the period of supply should be the maximum commercially possible. The period of supply is necessarily determined by the supply authority and may be as short as 12 or as long as 19 hours, depending upon the load characteristics of the district and upon the duration of the peak demand on the generating station or upon the grid. The value of T_1 is fixed as close to

TABLE 8.

Temperature Values for Radiator Heating Systems.

Circulation	Flow-temperature	Return temperature	Mean temperature	Room temperature	Mean temperature minus room temperature
	°F.	°F.	°F.	°F.	°F.
Gravity ..	180	140	160	65	95
Pump ..	180	150	165	65	100

the boiling-point as practicable—usually 20 deg. F. below—the boiling-point of the water at the top of the storage vessel being a function of the pressure at that point, and that again is a function of the height of the column of water which will exist between the top of the storage vessel and the surface of water in the expansion tank located at the highest convenient point in the building [head (ft.) × 0·433 = lb. per sq. in.]. Artificial heads may be arranged by the introduction of a mercury column or otherwise, but for reasons of safety the open-tank system is usually employed in the British Isles.

The lower temperature (T_2) which can be utilized to maintain the desired temperature in the heating, hot-water supply, or ventilating section, of the equipment, depends upon the type of heat-emitting surface employed within the building. For a radiator heating system the values usually selected are as given in Table 8.

Consideration has frequently been given to the possibility of employing lower mean temperatures, but the heat emission falls off rapidly and the dimensions of the radiators become impracticable. The lower value of the temperature cycle (T_2) may therefore be assumed to have an average of 160° F. for a radiator system installed in a building in which the temperature is to be maintained constant to the end of the discharge period, i.e. in a residence or hospital, hotel, block of flats, etc. Conversely, for an office block, factory, and similar buildings, that are vacated an hour or so before the end of the heat-discharge period, lower values may be employed, e.g. 130° F. or 140° F.

For the invisible-panel warming system, in which the pipes are embedded in the ceiling and operate at maximum temperatures of the order of 100° F., T_2 may be given this value for continuously occupied buildings, and 80° F. for buildings that are vacated daily prior to the end of the discharge period.

TABLE 9.

Capacity of Thermal-Storage Cylinders, in Gallons per Foot of Length or Height.

Diameter	Gallons	Diameter	Gallons	Diameter	Gallons
ft. in.		ft. in.		ft. in.	
3 0	44	6 0	177	9 0	398
3 3	51	6 3	192	9 3	420
3 6	60	6 6	208	9 6	443
3 9	69	6 9	224	9 9	466
4 0	78	7 0	240	10 0	490
4 3	89	7 3	258	10 3	516
4 6	99	7 6	277	10 6	540
4 9	110	7 9	295	10 9	566
5 0	123	8 0	314	11 0	595
5 3	136	8 3	334	11 3	623
5 6	148	8 6	348	11 6	650
5 9	163	8 9	377	11 9	675

For accurate calculations it should be noted that water at a temperature of 260° F. weighs 58·52 lb. per cub. ft., and it may be necessary therefore to make allowance for the greater volume when deciding the capacity of storage required for the installation.

A diameter of 10 ft. 3 in. should be regarded as the commercial maximum; larger diameters involve special construction.

(2) VERTICAL VERSUS HORIZONTAL CYLINDERS.

The decision regarding the shape of the vessel, i.e. horizontal or vertical, to be employed is largely governed by consideration of space available, and it should be noted that the flexibility of shape and of location within the building, regardless of convenient and suitable positions for chimneys, fuel delivery, and storage and ash removal, constitute some of the many advantages of the system. Other factors include the following:—

(*a*) Transport of the vessel to the site, unloading, and delivery to the final position it is to occupy.

(*b*) Circulation of water within the vessel (see par. 5 below).

(*c*) Minimum radiating surface for water content. (The ideal shape is naturally the sphere.)

(*d*) For installations in which immersion heaters are

employed, accommodation is required for the heaters, and space is required for the insertion and withdrawal of the heaters.

(*e*) Cost of the vessel.

(*f*) Availability of the exterior of the vessel for inspection for corrosion and leakage.

Completion of construction of vessels is now commonly effected on the site, either by riveting or by electric or acetylene welding, and the cost is not thereby materially affected.

Vertical cylinders clearly require relatively high chambers, and any increase of depth of the basement or sub-basement floor frequently leads to drainage difficulties and to heavy additional costs in the construction of exceptionally deep footings to retaining walls and to structural steelwork. Where the height is restricted, two or more vertical vessels may be installed, but this may materially increase the capital cost of the storage, lower the thermal efficiency, and increase the cost of the accessories, such as valves, gauges, immersion heaters (where used), etc.

A point to be noted in connection with the selection of vessels for use with groups of immersion heaters is the ratio of the cubic contents of the belt of water corresponding to the height of the group of immersion heaters, to the total cubic contents of the vessel above the belt (see Fig. 20).

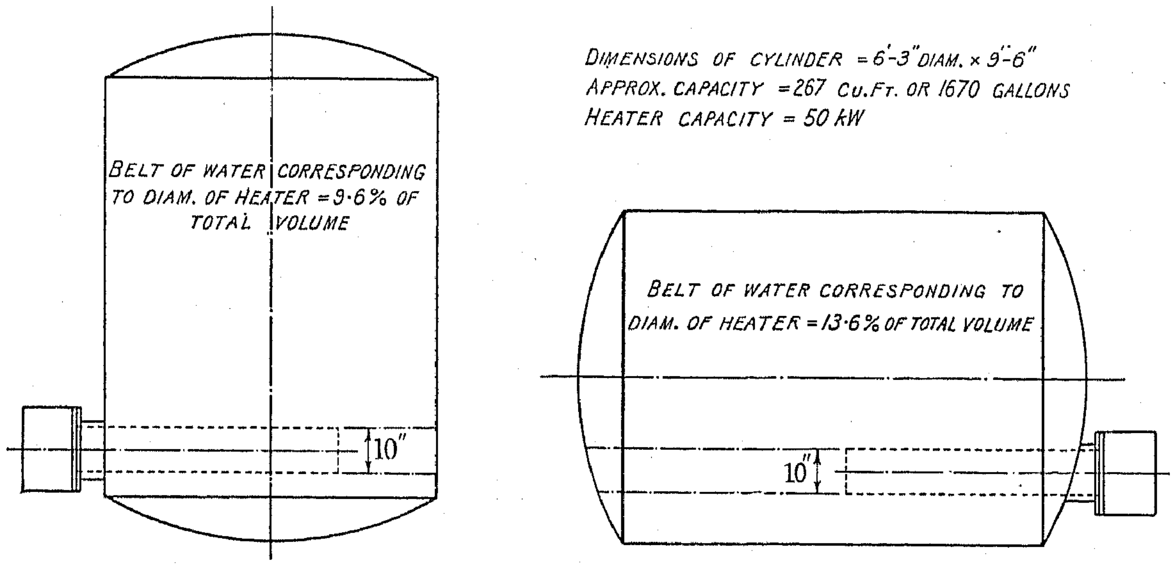


FIG. 20.—Comparison of the cubic contents of the belt of water corresponding to the diameter of an immersion heater group in a vertical and in a horizontal storage vessel.

(3) Supports for Large Storage Vessels.

Cradles for the support of horizontal storage vessels may be formed either of cast iron, reinforced concrete, or wood baulks. There appears to be little or nothing to choose between cast iron and reinforced concrete, but in either case it is desirable to insert a 3-in. thick liner of compressed machinery cork between the vessel and the supports in order to provide heat insulation and also for the purpose of forming a resilient bed to take up any inaccuracies in formation or alignment.

According to information kindly supplied by Newall's Insulation Co., Ltd., a 3-in. thickness of double-compressed machinery cork shows a compression of 8·5 per cent under a loading of 50 lb. per sq. in., 25 per cent at 75 lb. per sq. in. and 28·5 per cent at 100 lb. per sq. in. Grey* states that the normal safe loading of machinery cork is from 10 to 12 lb. per sq. in. or 0·65 to 0·77 ton per sq. ft. It is normal practice to figure on 0·75 ton per sq. ft., so that the compression is practically negligible.

Many vertical vessels have been built with the vertical sides extended down to floor-level and there riveted or welded to an angle-iron ring to form a base support, but recently the insurance companies have expressed a preference for the double-ended convex vessel having four feet either welded or riveted to the convex bottom so that any leakage may be readily detected and steps taken immediately to effect repairs and prevent corrosion. If slab cork is laid on the floor and the vertical sides are extended to floor-level by means of a removable skirting, a very neat and effective finish is secured.

(4) Expansion Water.

During the initial run of the season, when the storage water requires to be heated from the temperature of the main supply—say 45° F.—to the final temperature, which may be of the order of 250° F. to 300° F., the temperature range is 200° F.–250° F., but in the daily cycle, where the lower temperature may be 150° F. on a

TABLE 10.

Expansion of Water on the Application of Heat.

Temperature of water	Weight of 1 cub. ft.	Percentage increase in volume	Temperature of water	Weight of 1 cub. ft.	Percentage increase in volume
°F.	lb.		°F.	lb.	
45	62·42	—	200	59·97	3·93
80	62·23	0·30	220	59·64	4·45
100	62·02	0·64	240	59·10	5·32
125	61·65	1·55	260	58·52	6·25
150	61·18	2·14	280	57·90	7·08
175	60·66	2·82	300	57·26	8·27

* See Bibliography, (7).

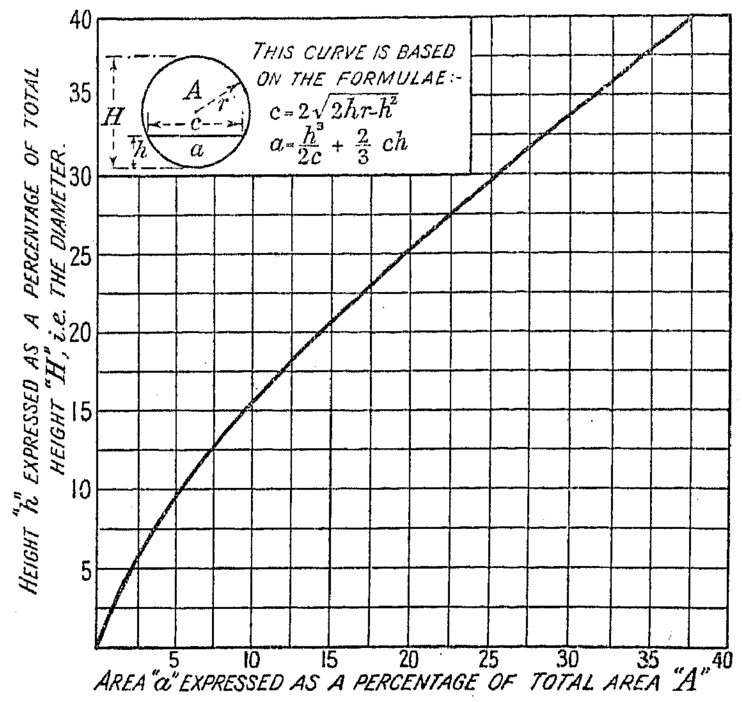


FIG. 21.—Graph connecting percentage of area of segment of a circle with percentage of diameter. For example, if the dead-water space required in a horizontal vessel is equivalent to $7\frac{1}{2}$ per cent of the total volume of the vessel, then the depth is practically 13 per cent of the height of the vessel.

radiator system or 90° F. on an invisible-panel warming system, the range will not usually exceed 160° F.–200° F. Even so, provision must be made to store the expansion water during the charging period and to restore it to the system during the discharging or cooling period.

Data relating to the expansion of water above 212° F. are seldom printed, and Table 10 has been prepared from information published by Carpenter.*

To discharge and also to vent the superheated water from the top of the storage vessel or from the water heater to the expansion tank, as is usual with fuel-fired installations, would lower the efficiency of the installation, for a large part of the heat would be lost; moreover, immediately the water commenced to rise in the expansion pipe and attain levels of lower pressure, steam would be formed which would result in noise. It therefore becomes necessary to provide space at the bottom of the storage vessel to accommodate a volume of water equivalent to the expansion contemplated, and so to arrange the heaters and the pipework that this water is not materially heated and that it is this water that is driven up the expansion pipe during the heating and expansion period. For a vertical cylinder the height required for the expansion water involves a simple calculation, but for a horizontal vessel it is somewhat more involved, and for ready reference the graph reproduced in Fig. 21 has been prepared.

* See Bibliography, (12).

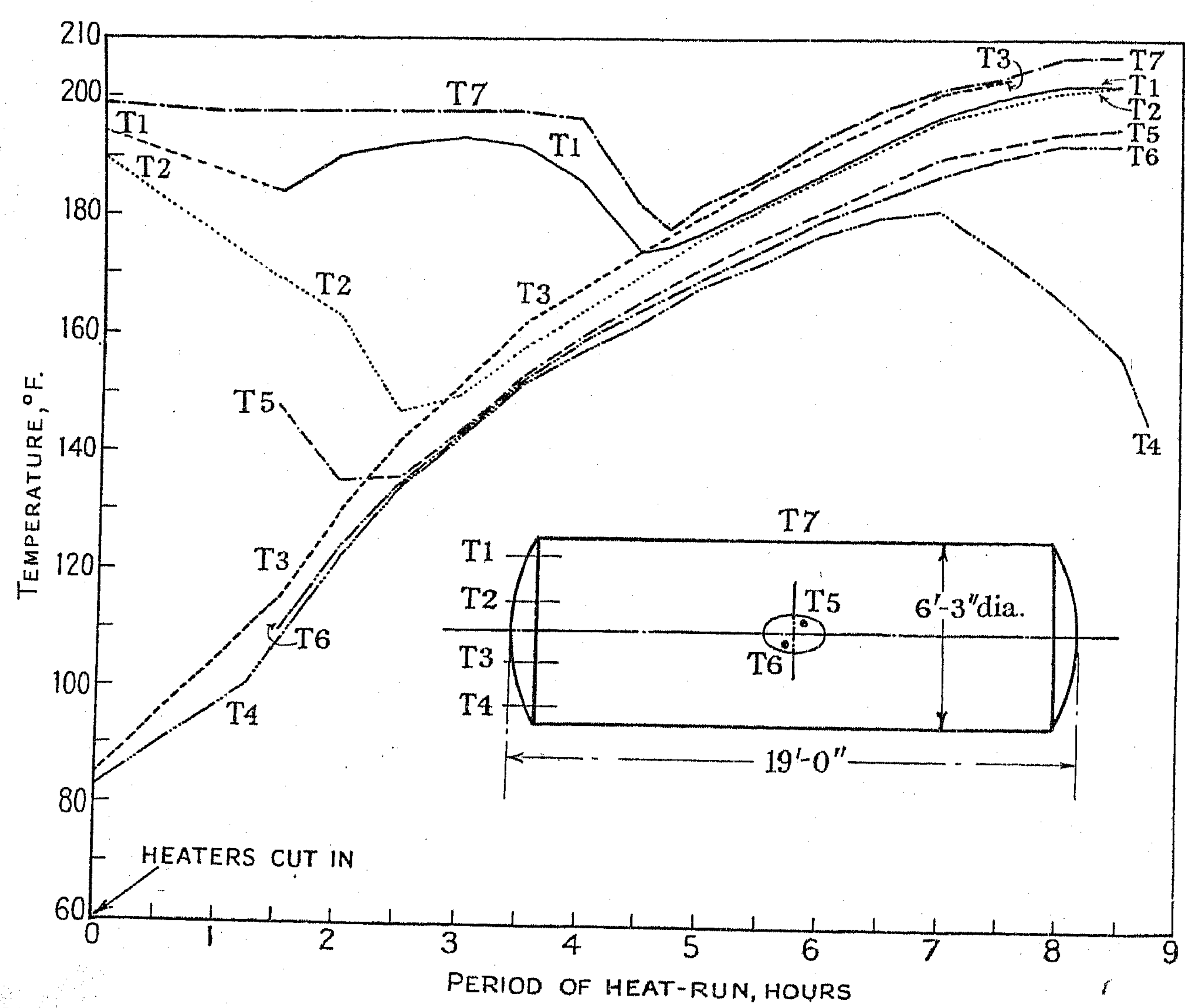


FIG. 22.—Graph of temperature distribution in a horizontal immersion-heater type thermal-storage vessel during the heat-run, No. 3 group cut out at 6.35, No. 4 group at 7, No. 1 at 7.54, and No. 2 at 8.3.

(Reproduced by the courtesy of Mr. Forbes Jackson.)

(5) Water Circulation and Temperature Distribution in Storage Vessels.

Points for consideration in the design of a storage vessel and its pipe connections include the following:—

(*a*) Adequate strength for the static head and suitability for the temperature range.

(*b*) At the completion of the heating or charging period, the temperature of the contents should be approximately uniform throughout.

(*c*) Clearly defined separation of the hot and cold strata should be obtained during the "discharge" period, so that high-temperature water is available for maintaining the temperature of flow water during that period.

(*d*) Quick response to any "boosting" charges that may be given during the day, i.e. a relatively small quantity of water should be heated through a relatively large temperature range, and this water should be directed to the upper part of the vessel, where it will be available for supply to the system. The undesirable converse condition would provide a large quantity of water very slightly heated, and, in bad cases, the "boost" may even upset the equilibrium of the contents, the result being that the water at the top of the vessel is at a lower temperature than at the commencement of the boost.

The temperature graphs reproduced in Figs. 22 and 23 for a horizontal and for a vertical cylinder respectively, provide useful information regarding temperature distribution under actual service conditions.

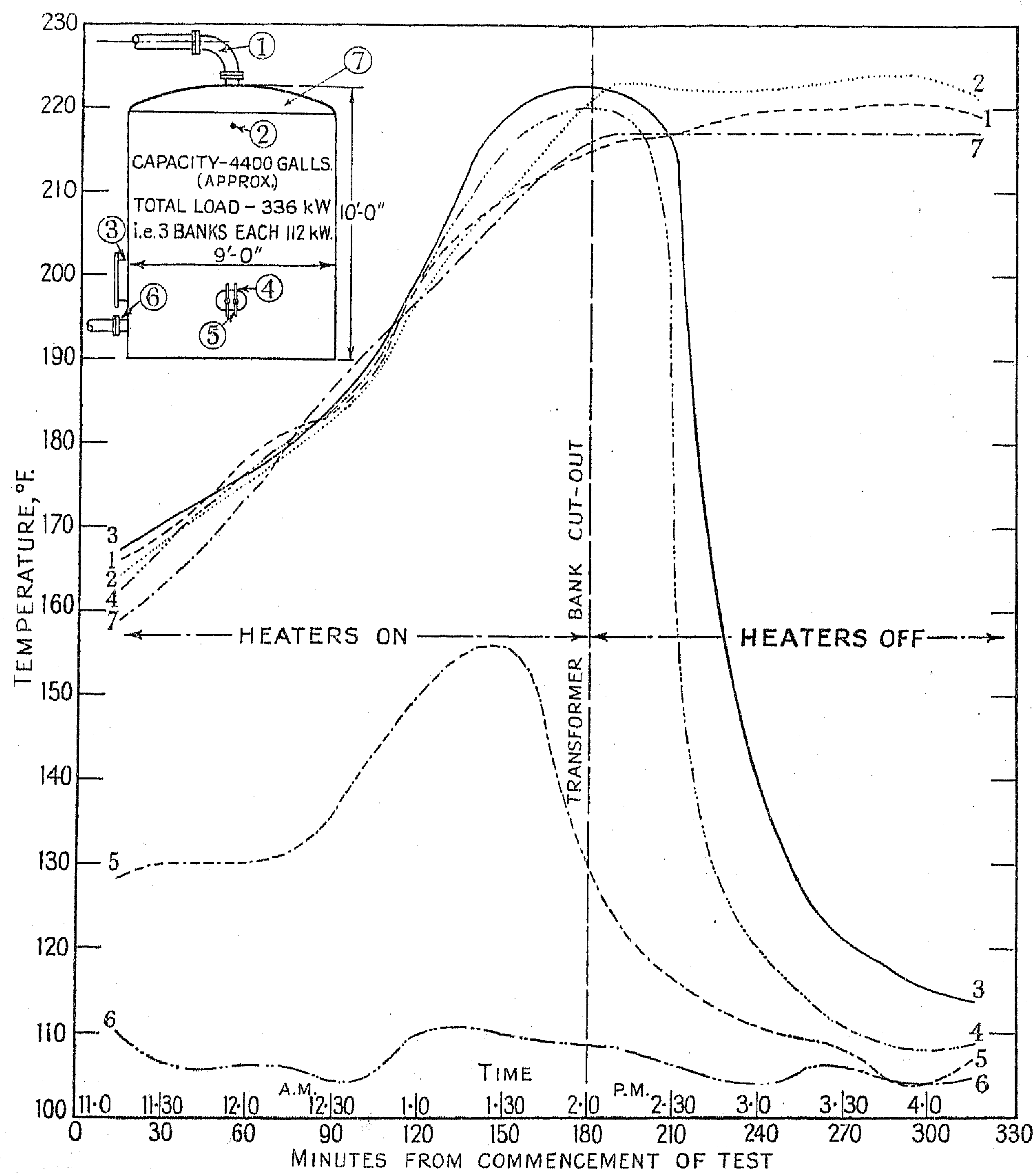


Fig. 23.—Graph of temperature distribution in a vertical immersion-heater type thermal-storage vessel during the heat-run.

One or more baffle plates may be introduced into the storage vessel for the purpose of controlling the direction of the circulation and in order to assist in the "layering" or the stratification of the hot, tepid, and cool water during various stages of the heat run. The circulation and stratification also affect the location of the thermostats, but this detail has already been discussed in an earlier paragraph.

(6) Heat Insulation of Storage Vessels.

Efficient heat insulation is a vital factor in the operation of thermal-storage plant, and the material used should satisfy the following requirements:—

(*a*) It must be able to withstand for an indefinite period the action of the maximum temperature to which it will be submitted.

(*b*) It must have a high heat-insulating efficiency.

(*c*) Weight is usually of little importance as it normally forms such a small proportion of the total weight.

(*d*) It must be easy to apply. Various forms of plastic material may be very suitable for steam pipes, but 1 sq. ft. of 3 in. thick 85 per cent magnesia is mixed with 1¼ gallons of water in order to apply it. On a 5 500-gallon vessel this represents 650 gallons or 6 500 lb. or (practically) 3 tons of water, the majority of which has to be evaporated after the vessel has been heated. The resulting atmospheric conditions are totally unsuitable for cables and switchgear other than of the deluge-proof type.

(*e*) It must be non-absorbent, since the presence of moisture almost invariably lowers the heat-insulating efficiency.

(*f*) It must have no corrosive action on the metal vessel and pipes.

(*g*) It must be insect- and vermin-proof.

(*h*) Its coefficient of expansion should be negligible.

(*j*) It should not readily support combustion.

(*k*) Its cost should be reasonable.

Materials frequently employed include asbestos paper, hair felt, wool felt, slag and glass wool, slab cork, aluminium foil, plastic and moulded magnesia, fibrous and felted rock wool, fossil meal, etc. With the kind assistance of the manufacturers Fig. 24 has been prepared. Some difficulty has been experienced in correlating data received from different firms, but the authors trust that the graphs give a reasonably true picture of the merits of the various materials.

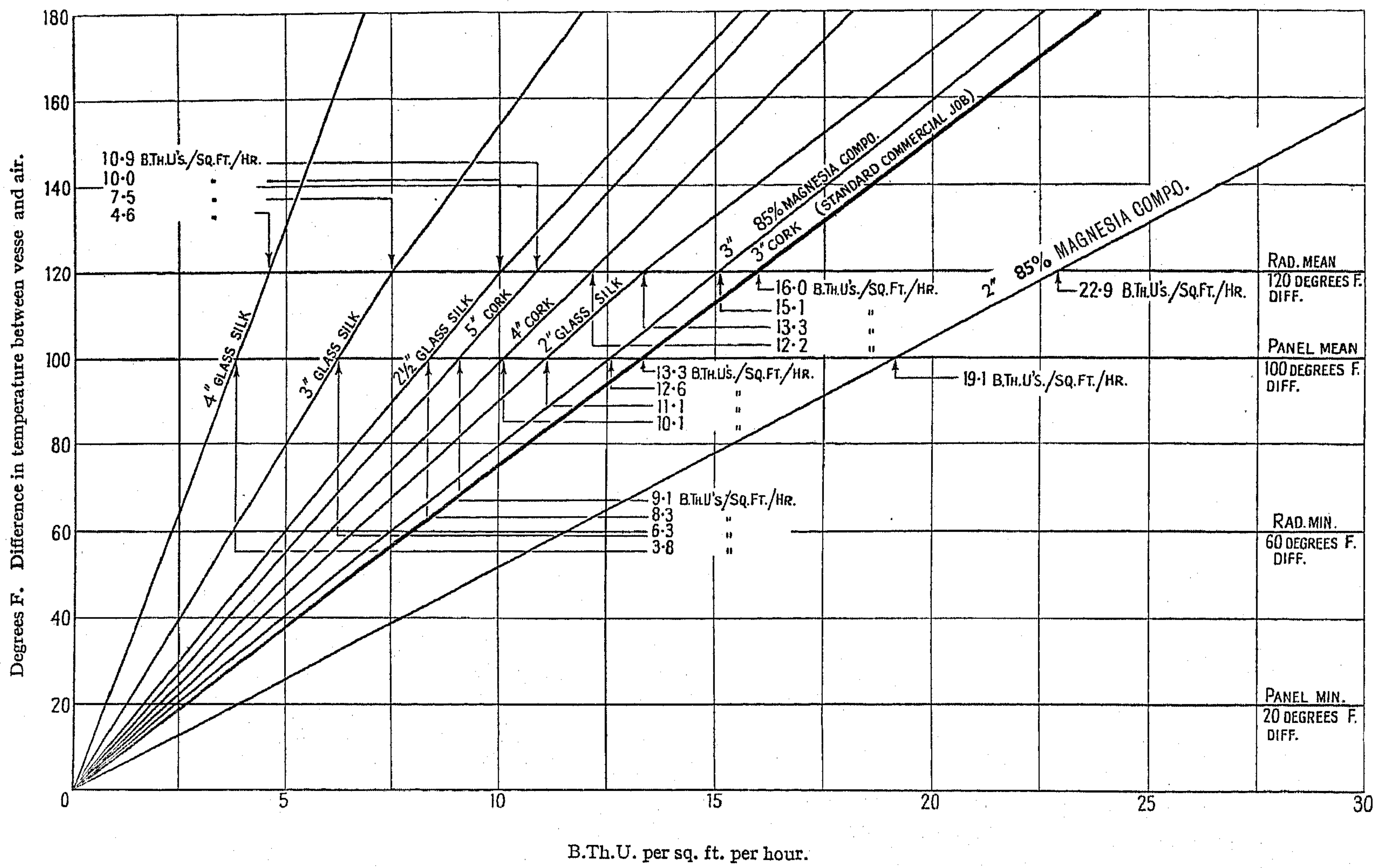


Fig. 24.—Graph of heat transmission through various types of heat-insulating materials to thermal-storage vessels.

Note.—The values for radiator and panel (mean and minimum) are based on a building height of 80 ft., a boiling-point of 280° F., a maximum vessel temperature of 260° F., and a room temperature of 80° F. Thus, if the max. and min. vessel temperatures are 260° F. and 100° F. respectively, the mean is 180° F., and if the room temperature is 80° F., then the difference is 100 deg. F.

As an example of the cash value of the heat losses, assume a temperature range of 250° F.–100° F., or a mean of 175° F. If the air temperature is 80° F. then the temperature difference is 95 deg. F. and the transmission loss is 12·6 B.Th.U. per hour per sq. ft. For a heating season of 5 100 hours it will be 64 000 B.Th.U. or 19 kWh.

A very satisfactory specification includes for lapping the vessel with 3-ply asbestos paper, insulating with 3 in. thick slab cork coated with Keene's cement, embedded in canvas and painted two coats of oil paint.

It is a convenience to the testing and operating staff if a series of small holes are provided in the heat-insulating jacket at 12 in. intervals vertically above one another, in which commutator-type thermometers can be inserted

and placed in contact with the shell of the storage vessel for the purpose of testing temperatures.

(7) QUANTITY OF WATER TO BE CIRCULATED PER HOUR BETWEEN MAIN STORAGE AND INDEPENDENT HEATER.

When the immersion-heater groups or the electrodes are housed in a vessel separate and apart from the main storage vessel, the quantity of water to be circulated through the heater requires consideration, for it has a material effect on the operation of the plant. At the commencement of the "charge," when the whole of the storage water has fallen to a low temperature, a substantial rise in temperature is desirable between the water drawn from the bottom of the storage vessel and the water returned to the top, and particularly is this so in the case of hot-water supply systems and combined heating and hot-water supply systems. Conversely, at the end of the "charge," when the temperature of the whole of the contents is approaching the maximum value, a small difference of temperature is desired, so that the temperature gradient throughout the vessel shall be the minimum possible and the average temperature of the contents shall be as high as possible.

One method of achieving this result would be to circulate an unvarying quantity of water and to commence with a very heavy "charging" rate, and to complete the "charge" at a low rate or loading, but this method is impracticable, since it is in direct conflict with the characteristics of the electrical resistance of water (which falls with rise of temperature), and it would involve excessive loading, larger cables, transformers, switchgear, and a complicated system of load control. The alternative method is to maintain the charging rate practically constant throughout the run, and to vary the rate of water circulation during the run, either by varying the duty of the pump or by providing a by-pass circuit under the control of a thermostat. By the latter method it is possible to re-circulate a substantial proportion of the water through the heater several times, thereby raising its temperature to a predetermined minimum before discharging it to the storage vessel, and securing the advantage of the full rating of the heater in the initial

TABLE 11.

Temperature Difference and Volume of Water Circulated Through a 294-kW or 1-million-B.Th.U.-per-hour Independent Heater.

Temperature difference in deg. F.	20	40	60	80	100
Lb. of water circulated per hour	50 000	25 000	16 600	12 500	10 000
Gallons per hour	5 000	2 500	1 660	1 250	1 000
Gallons per minute	83	41	27	20	16·7

TABLE 12.

Effect of Temperature Difference on Heat-Storage Capacity of the Vessel.

Temperature of top of vessel	Temperature of bottom of vessel	Temperature difference	Mean temperature of vessel	Panel flow temperature	Temperature range	Percentage storage capacity of vessel	Capacity required
°F.	°F.	deg. F.	°F.	°F.	deg. F.		
260	250	10	255	110	145	100	100
260	240	20	250	110	140	96·5	104
260	230	30	245	110	135	93·0	107
260	220	40	240	110	130	89·5	112
260	210	50	235	110	125	86·0	117
260	200	60	230	110	120	82·5	121

TABLE 13.

Expansion of Pipes Due to Increase of Temperature.

Temperature	Gauge pressure	Elongation in inches per 100 ft. run			
		Cast iron	Steel	Wrought iron	Copper
°F.	lb./sq. in.				
40	—	—	—	—	—
60	—	0·128	0·163	0·155	0·233
80	—	0·259	0·295	0·315	0·445
100	—	0·397	0·468	0·474	0·675
140	—	0·661	0·779	0·800	1·139
180	—	0·955	1·098	1·132	1·600
220	2·5	1·244	1·422	1·471	2·064
260	20·7	1·541	1·753	1·814	2·534
300	52·3	1·843	2·089	2·165	3·000

stages of the "charge." Thus, in a combined heating and hot-water system, the minimum temperature of the flow to the vessel may be fixed at 200° F., notwithstanding the fact that the temperature of the flow from the storage vessels may be as low as 100° F. and that the pump and the rating of the heater are designed to give a 30 deg. F. difference under normal operating conditions. This method has the merit of eliminating any rapid changes in temperature in the plant during the run, such as would be involved if gravity circulation were relied upon to provide a sluggish circulation and a substantial temperature difference in the initial stages of the charge, the circulation being accelerated when a predetermined temperature is reached. Speed control of the pump appears to be the other alternative, but this complicates the arrangement when induction motors are employed.

The manufacturers normally specify a temperature difference of 30 deg. F. across the heater in order to maintain an adequate circulation over the electrodes and prevent the formation of steam, and it will be seen by reference to Tables 11 and 12 that this value forms a very satisfactory compromise of the several requirements.

The formation of steam bubbles on the electrodes has the effect of providing an insulating jacket and will therefore cause the load to fluctuate more or less violently; it also reduces the life of the electrodes.

As the daily temperature cycle of the primary pipework installed in connection with an independent heater is of the order of 100° F.–200° F., care must be exercised to provide for its expansion and contraction, either by using double bends or by inserting expansion joints (see Table 13).

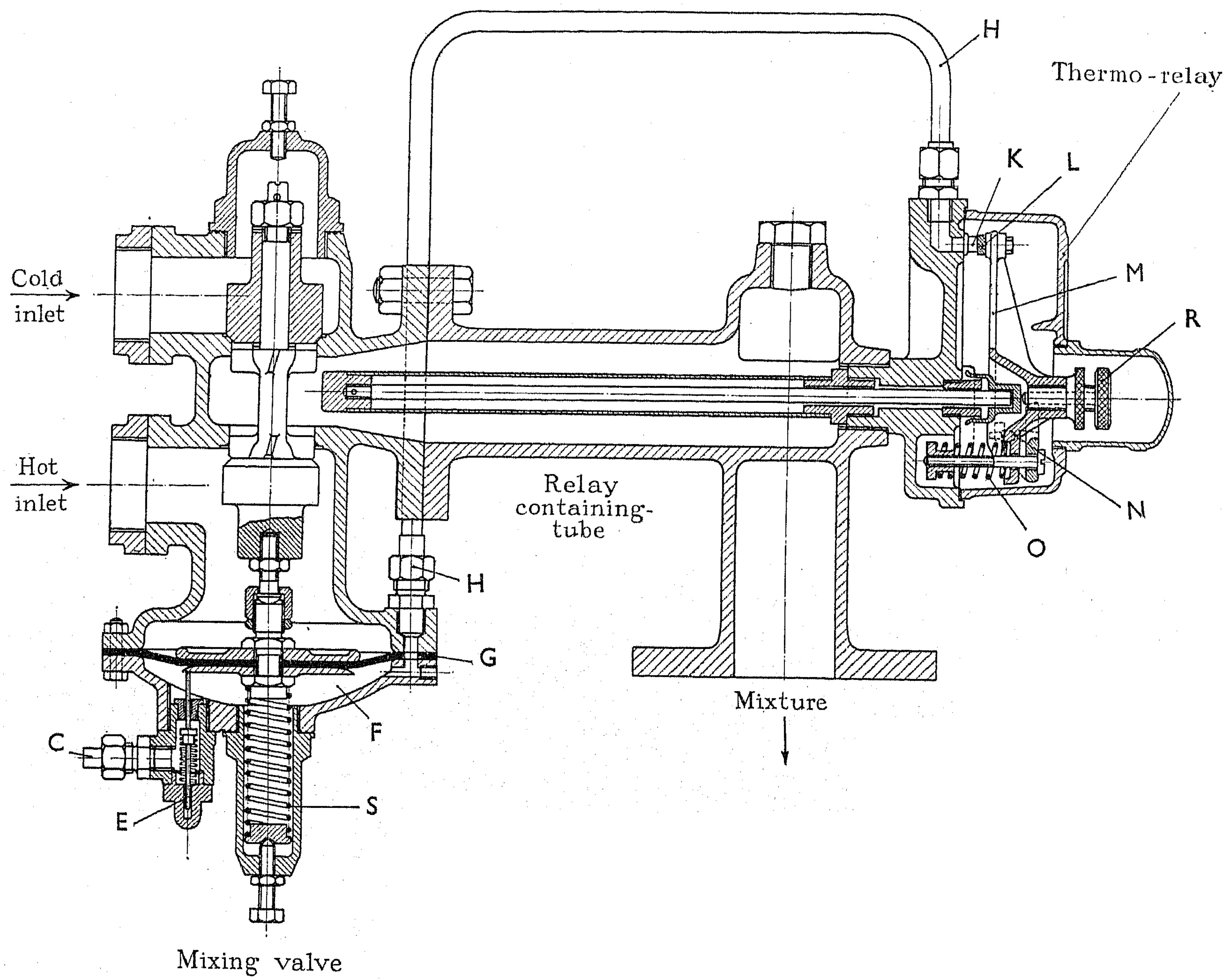


FIG. 25.—Water-mixing valve operated by pressure water and direct-acting thermostat.

(Reproduced by the courtesy of British Arca Regulators, Ltd.)

Water enters the diaphragm chamber F of the valve through the needle valve E and flows through pipe H to jet K of the thermo relay. Acting on the jet K is the pad L at the end of lever M which is pivoted at N and held in the pivots by spring O. An adjusting screw R in lever M makes contact with the end of the "Permant" steel rod. A rise in temperature of the water flowing in the horizontal tube will cause the tube to expand so that pad L approaches the jet K. This causes a pressure to build up in the pipe H and in the diaphragm chamber F and, with the assistance of spring S, the diaphragm moves the valve up to check the flow of hot and to increase the flow of cold water. The action is reversed on a fall of temperature of the water flowing through the horizontal tube.

(8) Water-Mixing Valves.

An important problem to be solved in all thermal-storage heating installations of the water type is that of maintaining a predetermined temperature in the flow pipe to the distributing system of the order of 140° F.–180° F. for a radiator installation and of 90° F.–110° F. for an invisible panel system, given a return temperature some 20–30 deg. F. below the values named, the hot water from the storage vessel varying in temperature between the limits of 250° F.–300° F. at the commencement of the run, down to 140° F.–180° F. at the end of the run for a radiator system and 80° F.–100° F. for an invisible panel system.

The essential equipment required for this duty is

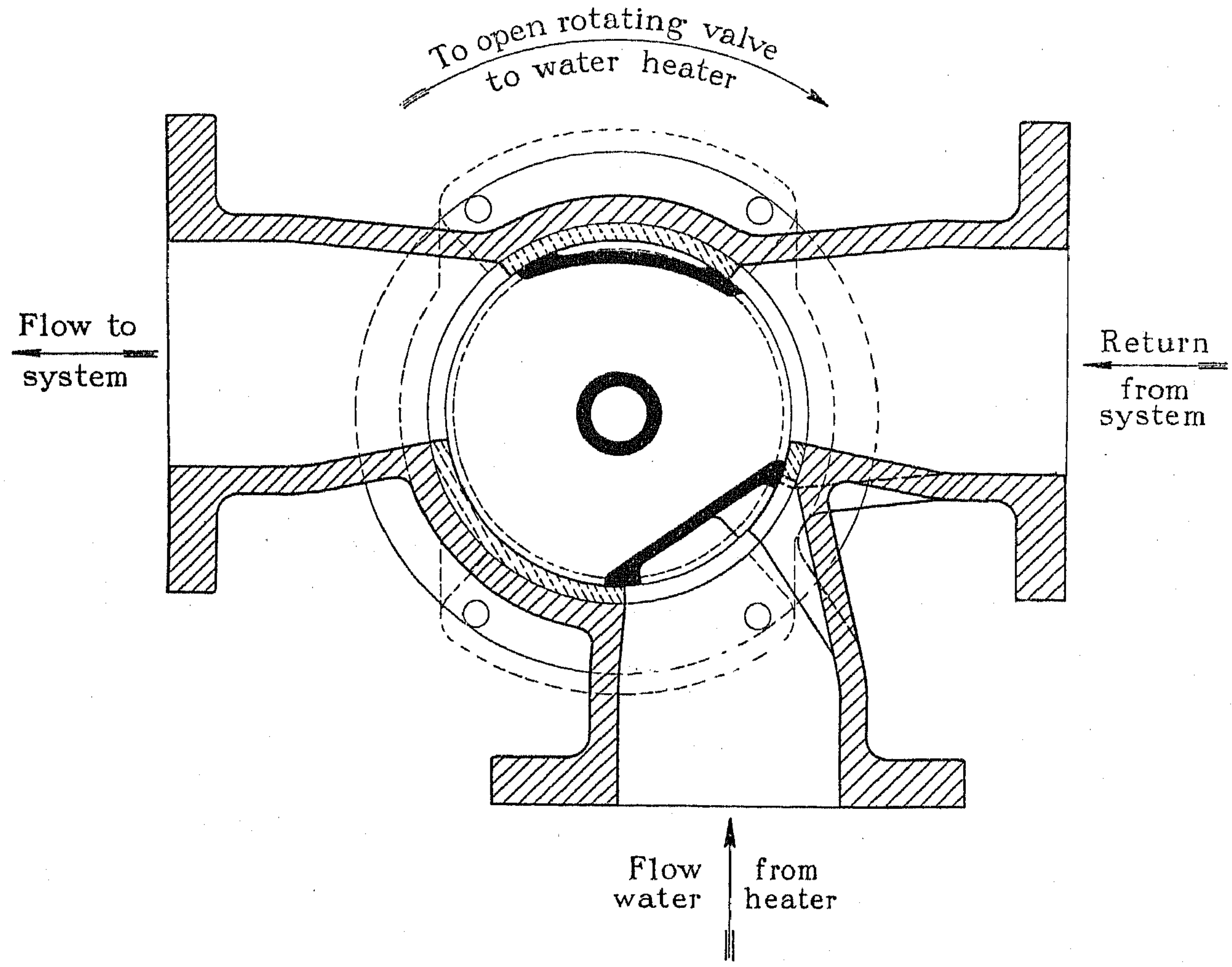


Fig. 26.—Motor-driven " Y " type water-mixing valve.

(Reproduced by the courtesy of the Magnetic Valve Co., Ltd.)

The motor is of the reversible type, controlled by a thermostat. It has a low-ratio gear for opening to the heater and a high-ratio gear for closing to the heater.

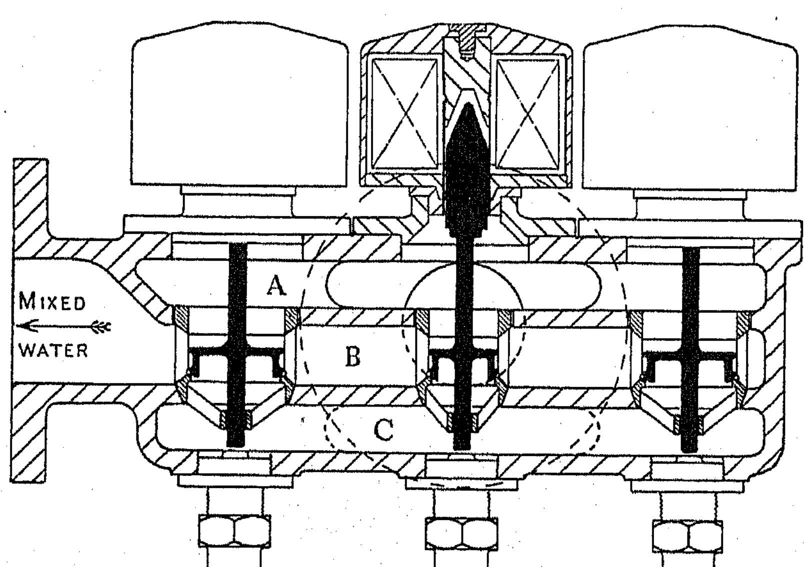


Fig. 27.—Triple-port solenoid—controlled water-mixing valve (modulator).

(Reproduced by the courtesy of the Magnetic Valve Co., Ltd.)

The cooled water returning from the warming system enters the chamber A, the hot water from the storage vessel enters the chamber C, and the proportion of hot and cool water entering the chamber B is determined by the position of the three solenoid-controlled valves, the coils of the valves being controlled by a triple-contact thermostat of the cascade type inserted in the main flow pipe.

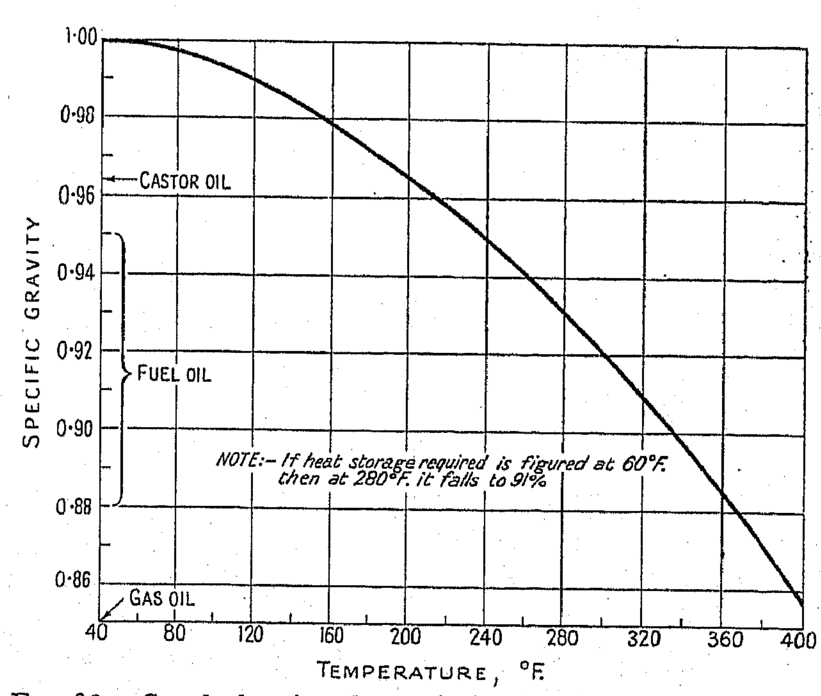


Fig. 28.—Graph showing the variation in the density of water at different temperatures.

Note.—At 200° F. the density is comparable with that of castor oil, and between 240° F. and 360° F. it is comparable with that of the fuel oils.

clearly an automatic mixing valve which is preferably of the 3-port type, designed to take in hot and cool water through two of the ports, and to discharge the mixture through the third port, the control of the valve being of the thermostatic type. The action of the thermostat may be employed to operate the control valves directly or to close and open electrical circuits which, in turn, start and stop motors or open and close valves of the solenoid type.

An example of the hydraulic type of mixing valve is shown in Fig. 25, of the motor-driven "Y" type in Fig. 26, and of the solenoid type or "modulator" in Fig. 27. For the last named, a special triple-contact thermostat is required having its contacts arranged in cascade formation, the arrangement being such that if the first valve cannot pass sufficient water to maintain the predetermined temperature, the second and, if necessary, the third valve, open.

In actual practice, the mixing valve does not mix the hot and cool water and discharge water of the intermediate temperatures, for they are extremely difficult to mix, due to their relatively substantial differences of density (see Fig. 28). In accelerated circulation systems the pump is frequently located in the flow pipe in order to secure satisfactory mixing of the two streams, and in gravity systems perforated cones have been introduced into the flow pipe for the purpose of breaking up and mixing the streams.

(9) Central Control of Flow-Pipe Temperature versus Individual Room Thermostats.

In his earlier paper* one of the authors emphasized the economy in current consumption attainable with direct electric heating equipment when controlled by thermostats located in the various rooms. This arrangement is of equal importance for the thermal-storage type of equipment, although the fact does not appear to be generally realized.

Single control of the flow-pipe temperature is now giving place to "zone" control in many thermal-storage installations, water differing in temperature by several degrees F. being circulated to various parts of the building. Typical examples include buildings on the Embankment where the river and street frontages vary in their relative heat requirements from day to day for the same outdoor temperature. Again, at Brighton, for a large block of flats, four zone controls are being provided as it is anticipated that the south frontage will show very marked variations in heat requirements between bright and dull days although the shade temperatures may be identical.

* See Bibliography, (2).

Charts showing the "on" and "off" periods for hot-water radiators fitted with solenoid valves, together with the temperatures maintained in the rooms, are reproduced in Fig. 29. They confirm the views expressed by the authors regarding this important detail.

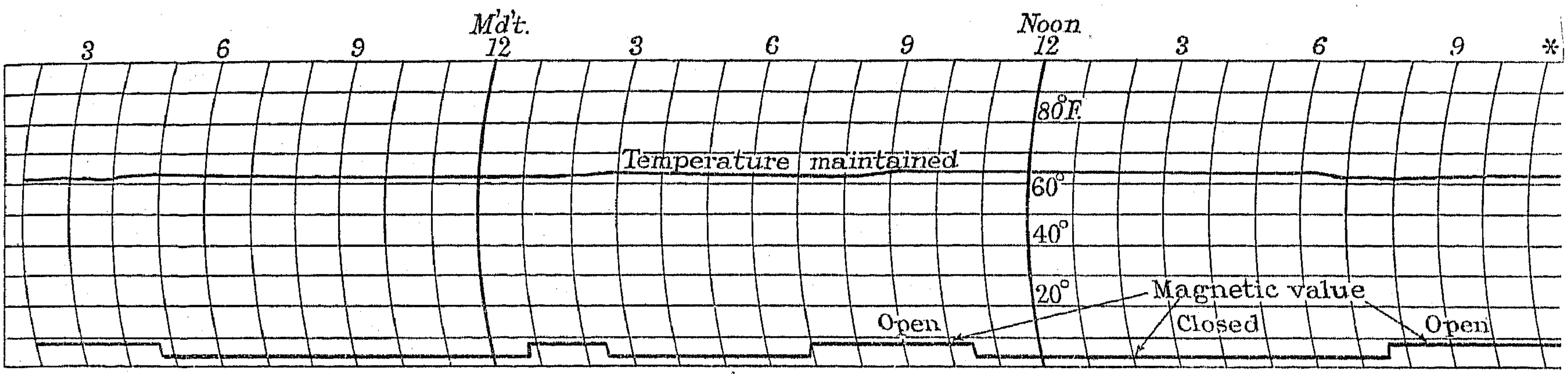


Fig. 29.—Graph showing temperature maintained and incidence of heat supply to a hot-water radiator connected to a central heating system, the radiator being controlled by a solenoid-operated valve and a room-type thermostat.
Note the comparatively long periods during which the supply of heat is shut off, although the room temperature is maintained.

Part IV. Domestic Hot-Water Supply Equipment.

(1) Types of Water and Their Critical Temperatures.

As is well known, water can be broadly classified into two distinct types, viz.

(*a*) Scale-forming, or hard, water.

(*b*) Soft, or corrosive, water.

There is no clearly defined line between the "hard" and the "soft" waters, the transition from the one to the other being one of degree only. Briefly summarized, water obtained from lakes, lochs, and moorland areas, is usually soft, whereas water obtained from deep wells is usually more or less hard. The analysis of water may change with the season if the water supply is obtained from several sources, such as local wells when the supply is available, and from moorland lakes or lochs during spells of drought or semi-drought, so that careful inquiries must be made and an analysis of one or more typical samples obtained from a specialist or from the water supply authority before the details of the installation are settled.

The installation of water-treatment plant has become much more common during recent years, not only for the purpose of supplying softened water to baths, basins, and sinks, but also to reduce the amount of scale deposited or the risk of corrosion in the pipes, heaters, etc., and again expert advice is recommended, since improper treatment may merely aggravate the operating conditions.

Regarding the temperature at which precipitation of the impurities included in the classification of temporary hardness occurs, a series of experiments were carried out by the National Radiator Co., Ltd., which indicate that the normal operating temperature has a marked effect

on the weight of solid matter deposited per 1 000 gallons heated. A temperature of 150° F. has frequently been regarded as "safe," but the experiments showed that in one case 25 per cent of the temporary hardness was thrown down at 120° F., whereas in another case only 11 per cent was thrown down at 120° F. and 33 per cent at 140° F. It will be noted that these values are very much lower than the more usual figure of 190° F. frequently employed for the "unit" type electric water-heaters, but it is understood that in several districts the thermostats have been adjusted to 150° F. with very satisfactory results.

It has been argued that the lower working temperature can have little effect on scale formation in electric water-heaters of the immersion type, owing to the relatively high surface temperature at which the heater tubes operate, and the authors hope that further information on this important point will be contributed in the discussion of the paper, since the temperature of the water has a vital effect on the quantity used and on the capacity of the storage vessels. In fact, it may develop into a vicious circle of lower temperature—more water used—and more water used—still lower temperatures—and larger and more expensive vessels. On the other hand, it is undesirable to discharge water at a temperature much in excess of 150° F. into lavatory basins, baths, etc., on account of the risk of scalding, damage to porcelain, enamel, etc., although a slightly higher temperature is desirable for sinks in order that grease may be readily removed from the various utensils.

(2) Consumption of Hot Water in Various Types of Building.

The formulation of accurate estimates of the quantity of hot water to be provided per hour and per day for any given building, when the project is in the planning stage, is one of the most difficult problems that the heating engineer has to contend with, for it is not one that is susceptible to exact calculation, but depends very largely on the idiosyncrasies of the occupants of the building and the number of people that the building will ultimately accommodate.

For example, there is the person who turns on both taps for his bath, carries on with other "dressing" operations, and then goes to the bath, only to find that it is too hot or too cold. He then runs a substantial quantity of the contents to waste and commences again. A second and even a third attempt may be made before the contents of the bath are at the desired temperature, and there is also the water required for washing out the bath after use. Again, there is the person who prefers to wash his hands in running water if the temperature is sufficiently low for the purpose, and this is a sound argument for maintaining the temperature at a minimum value of 145° F. at the draw-off taps. Two kitchens serving the same type and even the same number of meals per day will probably use vastly varying quantities of hot water per day, depending entirely on the habits and views of the kitchen staff. Laundries and hospitals provide an even more difficult problem.

It will be agreed, therefore, that the only possible solution of the problem is to provide very adequate storage capacity in order to meet the varying and often unexpected demands, and to provide adequate heating capacity to ensure rapid recovery or heating. Engineers who have experience of this class of load are satisfied that the diversity of demand justifies the higher loading and are quoting rates of the order of 720 kWh per £ for an unrestricted supply for thermostatically controlled heaters.

It is recommended that the calculations of consumption should always be made on an occupational basis rather than on the number of fixtures installed, because the scale of the number of persons per fitting is so variable.

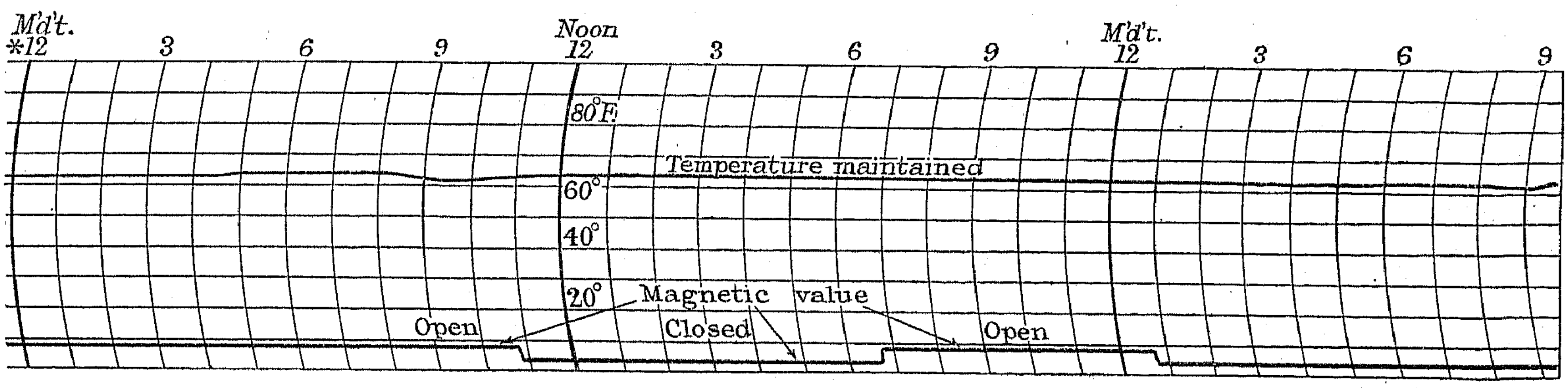


Fig. 29 (*cont.*).

A pattern of lavatory basin that is very generally used is the $21\frac{1}{2}$ in. × 11 in. at the top and requires the quantity of water given below for various depths:—

Depth of water (in.)	2	$3\frac{1}{2}$	$4\frac{3}{4}$	$5\frac{3}{4}$
Gallons	1	2	3	4

Very few people fill a basin to the brim, because the water is liable to swill over the sides, so that a reasonable allowance would be $2\frac{1}{2}$ gallons of "mixed" water in the basin.

Baths vary considerably in size, but a very common standard is 5 ft. 6 in. × 24 in. × 18 in. deep, and a reasonable depth of water in the unoccupied bath would be, say, 10 in. This would give an approximate volume of 5·62 cub. ft. and a "mixed" water content of 35 gallons.

Shower baths will probably be found to average from 2 to 3 gallons per minute or 120–180 gallons per hour.

Sinks also vary very considerably in size, but the common domestic bowl in general use holds 1 gallon, and

for a household of four people the quantity required will probably be found to average 3 gallons after breakfast, 3 gallons after lunch, 2 gallons after tea, and 4 gallons after the evening meal, or a total of 12 gallons of "mixed" water per day.

The usage per hour of the various fixtures and fittings naturally differs considerably, depending upon the scale, the type of building, etc., but Table 15 may be found useful as a guide.

Regarding the daily consumption, a family of four people of the normal suburban habits may be expected to average the following:—

	Gallons
2 baths at 20 gallons	40
20 lavatory basins full at $1\frac{1}{2}$ gallons	30
4 usages of sink at 3 gallons	12
5 buckets of cleaning water at 2 gallons	10
Total (say)	92

This net figure might be rounded up to 100 gallons or 1 000 lb. of water per day to allow for wastage, i.e. 25 galls. per head per day, and if the temperature-rise is averaged at 100 deg. F. the total heat required at 100 per cent efficiency is 1 000 × 100 or 100 000 B.Th.U., or 29·4 kWh.

According to an E.D.A. Report, the average consumption of 11 flats occupied by an average of 2·7 persons was 8 kWh per day, which is equivalent to 27·2 gallons at 100 per cent efficiency, 24·3 gallons at 90 per cent (local heaters), and 21·8 gallons at 80 per cent (central), or (say) 10, 9, and 8·1 gallons, per person respectively.

A more usual figure for the better class of flats is 20 to 25 gallons per day per occupant, including family and servants. The daily allowance for hospitals of the normal type, excluding laundry, is from 20 to 40 gallons per patient, depending upon the class of hospital. Office blocks without restaurants or canteens average 3 gallons per occupant and this should include cleaning.

TABLE 14.

Monthly Mean Temperatures of Cold-Water Supply.

Temperature of water (° F.) taken from a tap connected to the main at 20 Nottingham Place.

Month	1927	1928	1929	1930	1931	1932	1933
January ..	42·6	42·2	39·2	45·8	42·6	46·2	40·1
February ..	41·5	44·2	38·3	42·1	42·1	41·7	43·3
March	47·2	46·2	41·9	44·0	42·6	42·8	46·9
April	51·8	50·3	49·3	50·1	49·1	48·7	53·0
May	59·0	56·3	55·9	57·0	56·3	55·7	59·5
June	62·0	62·0	64·0	65·1	64·2	62·8	66·6
July	65·0	69·6	67·8	67·6	67·0	67·8	70·6
August.. ..	66·0	66·8	66·8	65·6	64·8	70·3	70·6
September ..	62·0	63·6	67·4	65·0	60·4	64·6	66·6
October ..	56·3	55·7	57·5	56·8	55·9	55·7	58·2
November ..	49·4	50·7	49·8	50·0	50·0	49·8	48·4
December ..	43·7	43·7	47·2	45·9	46·2	45·3	45·3
Yearly Mean ..	53·9	54·3	53·8	54·6	53·5	54·3	55·8

Mean temperature for the period of 7 years = 54·3° F.

Hotel and restaurant kitchens will probably be found to use 20 gallons of "mixed" water per hour per sink installed, and the usage will probably average 3 hours per meal for the vegetable sinks for the preparation of food before the meal, and the washing-up sinks to average 2 hours per meal after the service of the meal.

Cleaning is another very variable factor, but the domestic bucket holds 2 gallons of water, and a usage of 4 buckets per hour of "mixed" water per cleaner should provide an average value for this purpose.

Regarding the temperature of the cold-water supply, this varies according to the season of the year, and Table 14 has been prepared from information kindly supplied by the Metropolitan Water Board.

A convenient method of calculating the percentage of hot and cold water required to obtain a given quantity of water of a given temperature is included in Fretwell and Shutt's paper.* It is as follows:—

Cold-water temperature = 45° F.
Mixed-water temperature = 105° F.
Hot-water temperature = 150° F.

Then 105 − 45 = 60 parts of hot water.
And 150 − 105 = 45 parts of cold water

Then the total = 105 parts.

$$\text{And } \frac{60 \times 100}{105} = 57 \text{ per cent hot water.}$$

$$\text{And } \frac{45 \times 100}{105} = 43 \text{ per cent cold water.}$$

* See Bibliography, (8).

TABLE 15.

Hourly Demand of Hot Water during the Peak Period.

Fitting	Capacity, gallons	Gallons of hot water at 57 % of total capacity	Usage per hour
Baths	35	Say 20	2 to 3
Lavatory basins	2½ to 3	Say 1½	2 to 10
Showers ..	2 to 3 galls. per minute	Say 1½ to 2	10 to 20
Sinks (hotel, etc.)	5 to 10	Say 3 to 6	3 to 6
Cleaners' buckets	2	Say 1¼	3 to 4

One of the most interesting records that have been published is that given by Prof. Parker Smith in his I.E.E. paper. He gave the consumption of a 5-bedroom, 3-reception, and one-bathroom house occupied by six persons as 7 385 kWh per year for hot water from local electric heaters. Based on the average of 29·4 kWh per 100 gallons, this is equivalent to 25 000 gallons of hot water per year, or 76 gallons per day for the year averaged at 330 days to allow for holidays. For 6 persons it is equivalent to 12·6 gallons per person at 100 per cent thermal efficiency, or 10½ gallons at 85 per cent.

TABLE 16.

Average Daily Consumption of Hot Water in Various Types of Buildings.

Type of building	Daily consumption
Office	1½ to 2 gallons per person, plus 3 gallons per 1 000 sq. ft. of cleaning
Factory ..	3 to 6 gallons per head per day, depending on the class of manufacture
English house..	15 to 20 gallons per head per day
American house	30 to 35 gallons per head per day
English hotel ..	20 to 25 gallons per head per day
American hotel	35 to 40 gallons per head per day

At the Water Heating Conference convened by the E.D.A. in 1932, Mr. Selley stated that the cost of hot-water supply to 133 flats averaged 10d. per day per flat, the charge being at the rate of 800 kWh per £. This is equivalent to a consumption of 33 kWh per flat per day, and allowing for an overall thermal efficiency of the pipework and heaters of 77·5 per cent this represents the equivalent of 25·6 kWh or (say) 87·5 gallons per day averaged over the whole year. If the average number of occupants per flat was 3·5 people, this would represent an average daily consumption of 25 gallons of hot water per head.

Mr. Egerton has given* some useful data for the average consumption of hot water. These are reproduced in Table 16.

Diversity must also be considered in calculating the yearly consumption, and particularly is this the case for large blocks of good-class flats where it is not possible to contemplate 100 per cent occupation and usage of hot water for the whole year. Conversely, in the L.C.C. type of flat the yearly consumption will very nearly approximate 365 times the daily consumption, and laundry work may even increase it.

(3) HEAT REQUIRED FOR TOWEL RAILS IN BATHROOMS AND LAVATORIES.

In practically every modern building of the domestic type, heated towel-rails form an indispensable part of the central hot-water supply system to the bathroom and it is necessary to know the heat emitted and their effect on the overall efficiency of the system.

In a block of 80 flats equipped with one bathroom and one towel-rail per flat, the rails averaged 3 ft. × 3 ft. (3 rails and 2 legs). The oval tubes were made from 1¼ in. (o.d.) thin-wall tube and can be assumed as equal to 1 in.-bore iron pipe for the purpose of estimating the heat loss. For a room temperature of 60° F. and a water temperature of 160° F. the heat loss would be of the order of 80 B.Th.U. per lineal foot per hour for dull black pipe, and for the polished surface the loss would be 60 per cent or (say) 50 B.Th.U. per lineal foot per hour. The length of tube per towel rail was 15 ft., so that the total loss per flat would be 750 B.Th.U. per hour or 220 watts, and for the 80 flats 17·6 kW.* The load factor would be practically 100 per cent. Towel rails may be of the direct electric type or of the water-heated type, operating from the central hot-water supply system.

(4) LOCAL VERSUS CENTRAL STORAGE HEATERS.

In a building equipped with a continuous hot-water supply system the occupants demand adequate supplies of hot water instantly a tap is turned on in any part of the building. To supply this demand, cold water may be distributed to selected points throughout the building and there stored and heated electrically, the hot water being distributed to the baths, basins, sinks, etc., in the immediate vicinity of the various heaters by means of short branch pipes. The energy loss in the wiring to the heaters is extremely small and only occurs when the current is actually flowing, so that this source of loss is entirely eliminated immediately the temperature-control thermostat opens the circuit. There is, of course, the loss of heat from the storage vessels although they are more or less efficiently insulated. Table 17 has been prepared to illustrate this point.

Quite naturally, these figures can be criticized and the efficiency may be raised or lowered by varying the values employed, but the investigation indicates that an average efficiency of 90 to 95 per cent may reasonably be anticipated.

The manufacturers of a high-grade water heater kindly supplied the data given in Table 18.

Other points for investigation when considering the desirability of installing the local-heater system include the capital cost of the heaters, the annual cost of energy, the cost of wiring and plumbing connections, the availability of space for the accommodation of the heaters, their appearance, the cost of the periodical de-scaling

* See Bibliography, (9).

* This figure applies to an uncovered towel-rail.

required, and the effect of this process on the decorations and on interference with the amenities in the vicinity. The supply of electrical energy may be restricted to the off-peak hours, which involves the installation of larger and more costly vessels, and local time-switches or special wiring controlled by a single time switch, or it may be unrestricted, but if it is charged at a special rate then an independent wiring system, switchgear, and meters, are required.

TABLE 17.

Yearly Efficiency of Local Electrical Water-Heaters.

(1) Nominal capacity	(2) Approximate dimensions Diam.	Height or Length	(3) Approximate surface area	(4) kWh used per year	(5) kWh lost per year	(6) Annual efficiency
galls.	in.	in.	sq. ft.			
20	15	35	12·7	4 400	650	87
30	18	36	16·3	6 600	840	89
40	18	45	20·5	8 800	1 060	89
50	20	48	23·6	11 000	1 220	90
60	20	54	27·1	13 200	1 400	90
75	24	51	30·2	16 400	1 560	91
100	24	67	38·2	22 000	1 970	92
150	30	64	48·0	33 000	2 480	93
200	32	76	58·7	44 000	3 020	93

Notes to Table.

Col. 4:—kWh used per year are based on cylinder capacity (galls.) × 2·5 usages per day × 300 days per year, i.e. 750 usages per year × 100 deg. F. temperature-rise.

Col. 5:—kWh lost per year are based on a loss of 20 B.Th.U. per sq. ft. of surface per hour for 8 760 hours per year, i.e. 51·5 kWh per sq. ft. per year (3-in. cork slab or its equivalent would reduce the transmission to 12·6 B.Th.U. per sq. ft. per hour or 32·5 kWh per sq. ft. per year).

In the centralized method a complete system of circulating pipes must be installed so that hot water is instantly available at any point in the building whenever it is required, the " dead lengths " being usually restricted to a maximum distance of 6 ft. An effective circulation can usually be obtained by gravity, although in complicated systems it may be necessary to install a motor-driven pump. Galvanized-iron or copper pipes are commonly used for the distribution of the hot water throughout the building, and the effect of the lagging on both types is shown in Table 19. The apparent inefficiency of the lagging on copper pipes is due to the fact that heat is lost both by radiation and by convection from galvanized pipes, whereas with polished copper pipes, even when dull, the radiation loss is of a very small order, and the effective loss is almost solely due to convection. As the heat transmitted by the lagging is small in relation to that transmitted through the metal wall of the pipe, the latter may be neglected for both metals, the metal wall being regarded merely as a waterproof lining to the lagging. The actual loss of heat through the lagging, as differentiated from the percentage loss, is usually calculated as being the same for both metals.

If, as in one case noted by the authors in a Scottish hotel, the polished copper pipe is coated with distemper by the decorator " to match the surrounding work," as he termed it, the whole effect of the practical elimination of the radiation loss (due to the surface texture of the pipe) is lost, and the heat loss will be slightly in excess of that in the case of the bare galvanized pipe.

TABLE 19.

Heat Loss from Bare and Lagged Galvanized-Iron and Copper Pipes.

(Water at 150° F. and air at 60° F., or 90° deg. F. difference.)

Pipe diameter	Galvanized-iron: B.Th.U. per lineal foot per hour, Bare	Galvanized-iron: B.Th.U. per lineal foot per hour, Lagged	Galvanized-iron: Percentage saving due to lagging	Copper: B.Th.U. per lineal foot per hour, Bare, at 60 per cent of galvanized iron	Copper: B.Th.U. per lineal foot per hour, Lagged	Copper: Percentage saving due to lagging
in.						
½	48	10	80	29	10	67
¾	61	12		37	12	
1	70	14		42	14	
1¼	85	17		51	17	
1½	96	19		58	19	
2	113	23		68	23	
2½	135	27		81	27	
3	165	33		99	33	
4	203	41		122	41	

TABLE 18.

Daily Loss of Energy from Electric Water-Heaters.

(The kWh per day are based on the maintenance of a water temperature of 150° F. with a room temperature of 60° F., no water being drawn off.)

Capacity (gallons)	1½	3	5	12	15	20	30	40	60
kWh lost per day	0·47	0·74	0·79	1·38	1·50	1·65	1·88	2·11	2·30
Loading of heater (kW) ..	0·5	0·5	0·5	1·0	1·5	2·0	2·5	3·0	4·0

An analysis of the efficiency of the distributing pipework for three typical installations is given in Tables 20, 21, and 22, and if Barker's value of 95 per cent is employed for the efficiency of a "medium efficiency" electric water-heater, then the respective overall values are reduced to 49·5, 75, and 76·8, per cent, exclusive of any supply to towel rails.

TABLE 20.

Efficiency of a Central Hot-Water Supply System for a Large Suburban Residence.

Probable number of occupants 12
Total number of fittings:—
Baths 6
Lavatory basins 11
Sinks 7
Showers 1
Piping .. .. Copper
Probable maximum usage per day:—
12 persons, 20 gallons per head per day = 240 gallons or 2 400 lb. of water raised from 45° F. to 150° F. = 105 deg. F. rise = 252 000 B.Th.U. per day, or 74 kWh per day delivered into the fittings.
Storage .. .. 1 × 100-gallon cylinder in basement and 1 × 30-gallon cylinder in roof, or 130 gallons total.
Pipe losses:—

Pipe diameter	B.Th.U. loss per hour per foot		Total run of pipe in the installation	Total B.Th.U. loss per hour
	Bare	Lagged		
in.			ft.	
$\frac{1}{2}$	29	10	220	2 200
$\frac{3}{4}$	37	12	140	1 680
1	42	14	400	5 600
$1\frac{3}{4}$	51	17	20	340

Total loss per hour .. 9 820 B.Th.U. or 2·9 kWh
Total loss per day .. 235 700 B.Th.U. or 69 kWh
Efficiency:—

$$\frac{\text{Heat in water delivered to fittings } (252\ 000 \times 100)}{\text{Heat delivered to water at boiler } (235\ 700 + 252\ 200)} = 52 \text{ per cent}$$

TABLE 21.

Efficiency of Central Hot-Water Supply System for a Large Block of Flats.

Volume of building .. .. .. 394 000 cub. ft.
Probable number of occupants .. .. 132 flats averaging 3 persons per flat, or a total of 396 persons, say 400.
Total number of fittings:—
Baths 132
Lavatory basins 165
Sinks 142
Piping .. .. Galvanized iron

Probable maximum usage per day:—
400 persons at 15 gallons per day = 6 000 gallons or 60 000 lb. of water raised from 45° F. to 150° F. = 105 deg. F. rise = 6 300 000 B.Th.U. per day, or 1 850 kWh per day delivered into the fittings.
Storage, including stand-by plant to enable plant to be cleaned or repaired, without any interruption of the supply:—
2 × 950-gallon cylinders in basement, and 1 × 250-gallon cylinder on roof, or 2 150 gallons total.
Pipe losses:—

Pipe diameter	B.Th.U. loss per hour per foot		Total run of pipe in the installation	Total B.Th.U. loss per hour
	Bare	Lagged		
in.			ft.	
$\frac{1}{2}$	48	10	446	4 500
$\frac{3}{4}$	61	12	482	5 800
1	70	14	3 025	42 000
$1\frac{1}{4}$	85	17	354	6 000
$1\frac{1}{2}$	296	19	264	5 000
2	113	23	229	5 300
3	165	33	30	1 000

Total loss per hour .. 69 600 B.Th.U. or 20·5 kWh
Total loss per day .. 1·68 million B.Th.U. or 490 kWh
Efficiency:—

$$\frac{\text{Heat in water delivered to fittings } (6\ 300\ 000 \times 100)}{\text{Heat delivered to water at boiler } (1\ 680\ 000 + 6\ 300\ 000)} = 79 \text{ per cent}$$

TABLE 22.

Efficiency of a Central Hot-Water Supply System for a Block of City Offices.

Volume of building .. .. .. 1 769 000 cub. ft.
Floor area .. .. 154 000 sq. ft.
Probable number of occupants (at 100 sq. ft. per occupant) 1 500
Total number of fittings:—
Baths .. .. nil
Lavatory basins 136
Sinks 17
Piping .. .. Copper
Probable maximum usage per day:—
1 500 persons at 2·5 gallons per day = 3 750 gallons per day. Alternatively, 1 500 persons at 2 gallons per day = 3 000 gallons, plus 3 gallons per 1 000 sq. ft. for 154 000 sq. ft., or say 3 500 gallons.
Assuming that 3 500 gallons represents the average usage, this is equivalent to 35 000 lb. of water raised from 45° F. to 150° F., or 105 deg. F. rise, and the B.Th.U. required per day are 3 675 000, or 1 080 kWh.
Storage .. .. 1 000 gallons

Pipe losses:—

Pipe diameter	B.Th.U. loss per hour per foot		Total run of pipe in the installation	Total B.Th.U. loss per hour
	Bare	Lagged		
in.			ft.	
$\frac{1}{2}$	29	10	210	2 100
$\frac{3}{4}$	34	12	690	8 280
1	42	14	660	9 240
$1\frac{1}{4}$	51	17	180	3 060
$1\frac{1}{2}$	58	19	280	5 320
2	68	23	50	1 150
$2\frac{1}{2}$	81	27	60	1 620
3	99	33	140	4 620

Total loss per hour .. 35 390 B.Th.U. or 10·4 kWh
Total loss per day .. 850 000 B.Th.U. or 250 kWh

Efficiency:—

$$\frac{\text{Heat in water delivered to fittings } (3\,675\,000 \times 100)}{\text{Heat delivered to water at boiler } (850\,000 + 3\,675\,000)} = 81 \text{ per cent}$$

As this building will definitely be left unoccupied during the night and at the week-end, the introduction of a solenoid-operated valve into the circulation, operated by a time switch at predetermined hours, would materially improve the efficiency, by eliminating the pipe losses during the night and at the week-end.

The central water storage may be heated either by means of one or more groups of immersion heaters or an electrode water-heater or electrode boiler as already discussed, the actual selection depending largely upon the total capacity of plant to be installed.

In districts where water of the scale-forming type is employed and continuity of supply to the building is an essential condition of the service, the storage is usually subdivided into two or more units so that one section may be emptied down and de-scaled without serious inconvenience to the occupants of the building.

Hitherto, it has been considered to be unsafe and impracticable to store domestic hot water at temperatures in excess of the temperature at which it will be supplied to the circulating system, i.e. 150° F.–180° F., so that the danger of delivering steam from the draw-off taps has been eliminated in the event of the failure of the temperature-control devices. The higher temperature of 180° F. is usually only employed where the domestic supply is also utilized for an all-season supply of heat to the towel rails, which are now regarded as an indispensable fitting in every modern bathroom and lavatory, and this introduces three strata or layers of water into the storage vessel, i.e. the high temperature at the top, the 120° F.–140° F. return water lower down, and the cold supply make-up at the bottom.

In installations where the electrode water-heater is employed, it is usual to insert a copper-tube heater in the water-storage vessel and to separate the system into primary and secondary circuits so that water chemically treated to increase its electrical conductivity and to free it from scale may be circulated continuously through the electrode water-heater, the "raw water" being passed through the main storage vessel and heated by contact with the copper pipes of the primary circuit. By adopting this arrangement it is possible to "parallel" the copper-tube heaters and the main central heating vessel and to supply both services from the same electrode water-heaters, the copper-tube heaters being controlled by valves of the solenoid type which shut off the supply of superheated water to the hot-water supply vessels immediately the predetermined temperature of 150° F.–180° F. has been reached, although the electrode water-heater may continue to heat the main storage vessel supplying the heating system (see Fig. 30).

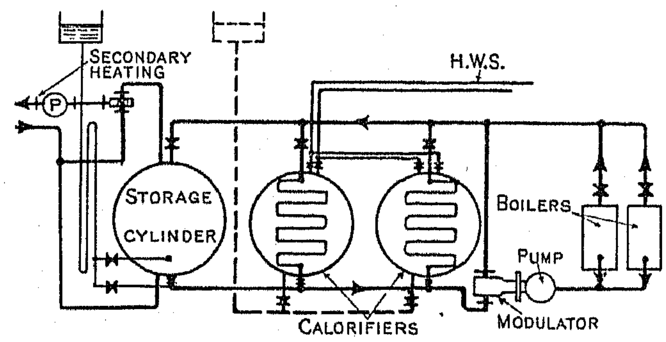


FIG. 30.—General arrangement of pipework to a combined central-heating and central hot-water supply system by two 300-kW, 400-volt, 3-phase water heaters.

A "modulator" and by-pass are fitted to the primary circuit, water being discharged to the storage vessels at a minimum temperature of 200° F.

(5) TYPES OF LOCAL WATER-HEATER AND THE PLUMBING WORK REQUIRED.

Of the three principal types of local water-heater at present available on the market, i.e. the displacement, local tank, and the pressure or semi-pressure, only the latter two are suitable for serving groups of basins, baths, sinks, etc., contemplated in this paper. Exception may be taken to the local tank type on the score of noise, increased height, low-pressure head at the draw-off taps, and impossibility of feeding the floor above, so that the pressure type is the one commonly installed in the larger buildings (see Fig. 31).

On account of the smooth bore, good appearance, and small outside diameter, copper pipes are frequently employed for the connections between the heaters and the fittings, the size being frequently reduced to $\frac{3}{8}$ in. for basins and $\frac{5}{8}$ in. for baths and sinks. The maximum length of the draw-off is normally restricted to 15 or possibly 20 ft. and where several heaters are connected to a common cold-feed pipe the branch to each heater is fitted with a stop-cock so that repairs, cleaning, etc., can be carried out on any heater without interrupting the supply to the remainder.

The items remaining for consideration are the following:—

(*a*) The hot water will expand on heating to the extent of approximately 3 per cent, and provision must be made for discharging this water from the heater and storing it until required, but preferably without warming up the cold-water supply to the lavatory, sink, etc., i.e. a separate cold feed is required from the feed tank to the heaters.

(*b*) If one thermostat only is fitted to the heater there

is always the risk, however remote, of the contacts sticking in the " closed " position and, if and when this fault occurs, the water will eventually boil, and pressure will be developed that must be released without danger to the occupants of the building.

(c) On the first filling of the heater and after subsequent emptyings for cleaning, etc., it will be filled with may be argued that in districts where the water is excessively hard the scale may securely fix the valve to its seat, but the same contention would apply with equal or greater force to the complete stoppage of the vent and feed pipes, and one is led to the conclusion that adequate maintenance of the installation of the local tank type is the only real safeguard.

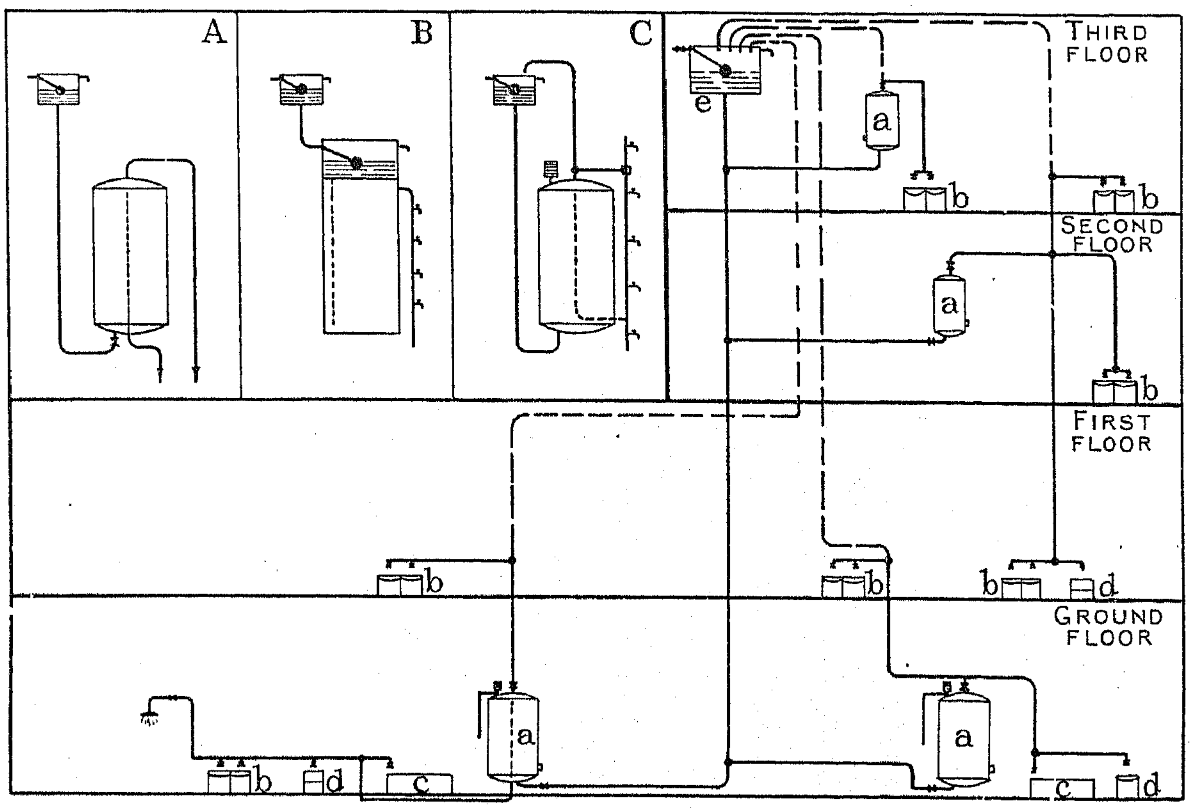


FIG. 31.—Types of water heater, and the arrangement of pipework to an installation of several " local " pressure-type water heaters.

A = displacement type.
B = semi-pressure or local-tank type.
C = pressure type.

a = pressure type.
b = basin.
c = bath.
d = sink.
e = feed and expansion tank.

air and a method of venting must be provided from the top of the vessel to enable it to fill with water.

This detail of venting of the pressure type of heater is of prime importance, and although in small installations comprising a single heater it presents no serious difficulty, the vent being teed on to the draw-off pipe and extended to discharge into the feed tank in the loft, attic, or roof space, it requires careful consideration in the larger buildings. Although the feed and the vent pipe are connected in parallel, the vent pipe rises over the top of the feed and expansion tank, and the expansion water will therefore discharge through the feed pipe only, so that if scale forms at the point where the vent pipe is teed on to the draw-off pipe, and the vent pipe becomes stopped up, there will be no external indication since the air will normally clear itself through the draw-off taps. The heater will then continue to function with the feed pipe only, and if the bore is seriously reduced by scale formation it may not be able to relieve the pressure adequately in the event of the thermostat " freezing " in the closed position.

Consideration of these facts appears to indicate that the vent pipe on the pressure type of heater is unreliable, frequently costly, and sometimes difficult to install, and that the only reliable and practicable method is to provide a safety valve for each heater, the valve being piped to a point where the steam or boiling water may be safely discharged if and when it functions. It

(6) Annual Consumption of Energy and Fuel by Domestic Hot-Water Supply Installations.

For the purpose of calculating annual costs, a unit of 100 000 gallons of water is found to be convenient. The weight of this quantity is 1 million pounds, and if it is raised through 100 deg. F. the total heat input at 100 per cent efficiency is 100 million B.Th.U. To obtain the actual input under practical working conditions it is necessary to adopt a value for the overall efficiency and it has already been shown that local electric heaters normally average 90 to 95 per cent.* For the centralized heaters the efficiency of the distributing pipework has been shown to be of the order of 52, 79, and 81, per cent respectively for three typical installations, and for the electric, gas, coke, and oil forms of " boiler," the values given by Barker may be employed, viz.

Type of heater	Best	Medium	Worst
	per cent	per cent	per cent
Electricity . .	98	95	90
Gas	85	75	65
Oil	80	65	50
Coke	75	55	35

* Where the " usage " of water is small the yearly efficiency may fall to 50 per cent, or even less.

Having obtained a value for the combined efficiency of pipework and heater by the method indicated, the fuel required per 100 000 gallons can be obtained directly from Table 23.

(7) Water-Heating Loads From May To October.

There is undoubtedly a very substantial hot-water supply load to be obtained during the summer months at rates of the order of 800–1 000 kWh to the £, because in many buildings this service is combined with the central heating system, and the possibility of shutting down the whole of the coal- or oil-fired plant at the end of the heating season would be welcomed by people who still require an ample supply of hot water during the summer months.

Table 23.

Annual Consumption of Fuel and Energy for Domestic Hot-Water Supply Systems per 100 000 Gallons of Water per Annum, Raised Through 100 deg. F., i.e. 100 Million B.Th.U. per Annum.

Overall efficiency	Tons of coke at 12 500 B.Th.U. per lb., or 28 million B.Th.U. per ton	Tons of oil at 19 200 B.Th.U. per lb., or 43 million B.Th.U. per ton	Therms of gas at 100 000 B.Th.U. per therm	Units of electricity at 3 400 B.Th.U. per kWh
per cent				kWh
100	3·56	2·32	1 000	29 400
95	3·76	2·43	1 060	30 800
90	3·96	2·58	1 110	32 700
85	4·19	2·73	1 180	34 500
80	4·45	2·90	1 250	36 800
75	4·75	3·10	1 340	39 200
70	5·08	3·32	1 430	41 800
65	5·48	3·58	1 540	45 200
60	5·94	3·85	1 660	48 700
55	6·50	4·23	1 810	53 200
50	7·13	4·65	2 000	58 500
45	7·93	5·18	2 220	65 100
40	8·90	5·82	2 500	73 000
35	10·0	6·65	2 860	83 500
30	11·9	7·75	3 320	97 500
25	14·2	9·30	4 000	110 700
20	17·8	11·6	5 000	146 000
15	23·7	15·6	6 650	195 000

The storage cylinders or calorifiers are usually of ample capacity to accommodate a bank of immersion heaters, and these would take over the duty of providing the supply of heat during the time that the fuel-fired plant is out of commission, the supply of energy being either without any time restriction at all or possibly only for comparatively short periods.

(8) Heat Required for Swimming Pools.

The universal employment of filtering plant for the continuous purification of the water of the modern swimming pool, in lieu of the former bi-weekly complete change of water, has very greatly simplified the heating problem, for it now resolves itself into a question of preventing the water from cooling, whereas, in the older method, it involved the warming of very large quantities of fresh water in the shortest possible time.

The water capacity of typical pools varies considerably. A bath having the dimensions 100 ft. × 40 ft. × 8 ft. 6 in. at the deep end holds 120 000 gallons; a smaller bath will probably be 75 ft. × 30 ft., will have a maximum depth of 6 ft. 6 in., and will hold 80 000 gallons.

As the majority of the pools are used only during the summer, a minimum supply temperature of 50° F. can usually be relied upon, and the heat required to raise 100 000 gallons of water through 22 deg. F. is 22 million B.Th.U. or 6 500 kWh. This initial warming is only required for the first filling at the commencement of the season and it can be spread over several days without serious inconvenience, in order to limit the capacity of the heaters to an economical size.

The daily loss of heat from an enclosed bath has been found by experience to be of the order of 1½ to 3 deg. F., so that for a 100 000-gallon pool containing 1 million pounds of water the total daily input of heat would be from 450 to 900 kWh. This load can be taken at any time convenient to the supply authority, as the plant will be of the automatic type and the process of heating simply consists of passing the bath water through the heater until the temperature is raised by 1½ or 2 deg. F.

Figures kindly supplied to the authors for a 150 000-gallon enclosed bath for the period 20th May to 20th November (6 months) show a consumption of 107 814 kWh, which is equivalent to 600 kWh per day or at the rate of 400 kWh per day per 100 000 gallons, the heat loss being at the rate of 1·37 deg. F. per day. With the experience gained in the operation of the plant, it is anticipated that the loss of " scum " water will be reduced and that better figures will be obtained in the future.

Plant of the type indicated has been installed at Watford, at the Empire Swimming Pool at Wembley, and elsewhere, and is now in successful operation.

Part V. Air-Conditioning Equipment.

(1) Quantity of Air to be Conditioned.

The fundamental basis of any scheme for the conditioning of the air to be supplied to a building and for the removal of the vitiated air from the building is the volume of air to be handled per hour or per minute, but the basis for the determination of this quantity varies considerably.

Vitiation of the air may be due to noxious trades or cooking smells, or to heat generated by people, machinery, illuminants, etc., or to the sun shining on the glass or walls or roofs of buildings, or to the concentration of people in confined spaces, or to the excess or deficiency of moisture content, and many other factors.

The cubic contents of a room or building frequently bears a definite relation to the occupancy or to the purpose for which it is used, so that air quantities may be based on the number of air changes required per hour. Constants frequently employed for this method of

determining the quantity of air to be handled are shown in Table 24.

As the specific heat of air at constant pressure has the value of 0·2145, and as the weight of a cubic foot of air and water vapour at 60° F. is 0·7589 or approximately 0·76 lb., it follows that 1 B.Th.U. is required to raise approximately 55 cub. ft. of air through 1 deg. F. The heat emitted by the average adult person in repose or occupied in a sedentary manner is usually taken at 350 B.Th.U. per hour or (say) 100 watts, and Table 25 has been based on these constants, employing the expression

TABLE 24.

Quantity of Air Required per Hour, Based on Air Changes.

Private libraries ..	4	Public lavatories ..	10
Textile mills	4	Hotel kitchens	15 to 20
Private offices ..	4	Laundries	20
Public offices ..	5	Engine and boiler rooms	20
Small meeting halls	4 to 6		

$$\text{Temperature-rise} = \frac{\text{B.Th.U. per hour} \times 55}{\text{Cubic feet of air per hour}}$$

The minimum standard adopted by the London County Council for premises licensed for music and dancing is 1 000 cub. ft. of fresh air per hour per person, but even on this scale the temperature-rise is liable to be excessive in summer although it will provide reasonably good conditions in winter if the heat from the lighting equipment and other sources is not excessive. For this reason many buildings are equipped with 2-speed fans so that in winter the air is supplied and warmed on the basis of 1 000 cub. ft. of air per hour per person, but in summer, when it is desired to prevent the temperature rising to an excessive degree, the fan is driven at the higher speed and may deliver air on the basis of 2 000 or 2 500 cub. ft. of air per hour per person.

TABLE 25.

Quantity of Air Required on the Basis of Temperature-Rise and Vitiation.

Air supply per person		Temperature increase due to body heat, but excluding transmission and other losses of heat from the structure	Parts of CO_2 in 10 000 parts of air (fresh air = 4 parts in 10 000)
Cubic feet per hour	Cubic feet per minute	deg. F.	
6 000	100	3·2	5·0
5 000	83	3·8	5·2
4 000	66	4·8	5·5
3 000	50	6·4	6·0
2 500	42	7·7	6·4
2 000	33	9·6	7·0
1 500	25	12·8	8·0
1 000	16·6	19·2	10·0
750	12·5	25·6	12·0

In order to connect the floor area of the building with the probable occupancy, Table 26 has been prepared from the information contained on page 15 of the Annual Report of the Advisory Council of the Building Industry for the administrative year 1931–1932.

(2) QUANTITY OF HEAT REQUIRED FOR CONDITIONING AIR.

Considerable confusion exists at the present time in the meanings attached to the words "*ventilation*" and "*air conditioning*." Ventilation may involve the supply or the removal of air from a building or room, and this may be achieved either by natural or mechanical methods or by a combination of the two, e.g. it may be supplied by a fan and extracted by some form of cowl or sheet-iron ventilator, or, of course, by a motor-driven fan. If, in addition, the air supply is warmed in winter it may be said to be "conditioned" in the broadest sense of the word, but in the strict technical sense the term "conditioned" should be reserved for plant that "conditions" both the temperature and the moisture content, and also removes impurities such as dust, microbes, oil fumes, etc.

TABLE 26.

Maximum Occupancy of Buildings.

Type of building	Floor area per person
	sq. ft.
Theatres, music halls, etc.	6
Dance halls, gymnasiums, etc.	10
Restaurants, hotel lounges, class rooms, exhibitions, etc.	25
Retail stores, showrooms, work rooms, common lodging houses, etc.	75
Offices, hotels (upstairs rooms), flats, hospitals, residences, etc.	100
Warehouses and storerooms	150

The quantity of heat required for warming the air supply may be calculated by transposing the expression given in the previous paragraph, i.e.

$$\text{B.Th.U. per hour} = \frac{\text{Temperature-rise} \times (\text{cub. ft. per hour})}{55}$$

but the calculation for conditioning for moisture content is rather more complicated. Air at 30° F. and 100 per cent relative humidity contains only 1·94 grains of moisture per cub. ft., but if it is warmed up to 65° F. it requires 6·78 grains per cub. ft. to saturate it, so that unless moisture is added at the time of warming the relative humidity at the higher temperature is reduced to

$$\frac{1\cdot94 \times 100}{6\cdot78} = 28\cdot6 \text{ per cent.}$$

This is an abnormally low value for the moisture content of the air and will cause excessive evaporation of moisture from the throat, nose, and the exposed surface of the skin, but at the same time the evaporation of

moisture in large quantities is an expensive process. It is therefore usual to effect a compromise and to base the calculation for moisture content not on the extreme weather condition that only occurs infrequently, but on an outdoor temperature of, say, 40° F. and 75 per cent relative humidity, which corresponds to a moisture content of 2·14 grains per cub. ft. This will provide a relative humidity of 31·6 per cent at 65° F., which is still very low, and the desirability of adding moisture is obvious.

The values frequently specified for indoor conditions are 65° F. and 60 per cent relative humidity, which corresponds to a moisture content of 4·1 grains of moisture per cub. ft., so that it is necessary to design the plant to evaporate a maximum of 2 grains per cub. ft. of air supplied, the actual operation being under automatic control.

The total heat required for warming and adding moisture to the air supply is summarized in Table 27, which has been prepared on the basis of 7 000 grains of water per pound, and a value of 1 050 for the latent heat.

TABLE 27.

Heat Required for Conditioning Air Supply.

(Initial conditions assumed to be 40° F. and 75 per cent relative humidity, containing 2·14 grains per cub. ft., and final conditions to be 65° F. and 60 per cent relative humidity, 2 grains per cub. ft. being added. Minimum air temperature assumed to be 30° F.)

Cubic feet of air		Heat load for the air		Moisture evaporated per hour	Heat for evaporation of moisture		Total heat required	
Per hour	Per minute	B.Th.U. per hour	kW		B.Th.U. per hour	kW	B.Th.U. per hour	kW
				lb.				
60 000	1 000	38 200	11·2	17	18 000	5	56 200	16
150 000	2 500	95 500	28	43	45 000	13	140 000	41
300 000	5 000	191 000	56	86	90 000	26	281 000	82
450 000	7 500	285 000	84	129	135 000	39	420 000	123
600 000	10 000	382 000	112	171	180 000	53	562 000	165
900 000	15 000	573 000	168	236	270 000	80	843 000	248
1 200 000	20 000	764 000	224	342	360 000	106	1 124 000	330
1 800 000	30 000	1 146 000	336	513	540 000	159	1 686 000	495
3 000 000	50 000	1 910 000	560	860	900 000	265	2 810 000	825

Inspection of Table 27 clearly indicates that the addition of moisture control to the plant increases the heat requirements by 47 per cent, and this is the reason for its infrequent adoption in this country up to the present time. In America, where temperatures frequently fall below zero and indoor temperatures of 68° F. and 70° F. are maintained, it will be seen that the dryness effect is greatly aggravated and the addition of moisture practically becomes essential.

(3) RESISTANCE-TYPE AIR HEATERS VERSUS WATER-HEATED AIR HEATERS WITH THERMAL-STORAGE PLANT.

In an earlier part of this paper it was emphasized that the maintenance of the comfort condition within the occupied building resolved itself into the problem of the prevention of excessive cooling of the building, rather than one of warming the building.

Conversely, the process of conditioning the air supply to the building is essentially a straight heating problem without fortuitous assistance of any kind, for there is no thermal capacity for heat storage, no casual heat, and no diversity. The heat required to warm the air and to evaporate the moisture has to be supplied whenever the air is required, although the maximum duty is only demanded when the outdoor temperature drops to the minimum value. The mean winter temperature in the London district is 44° F., and is equivalent to an average load of 60 per cent of the maximum. It is essentially a day load. Moreover, it is not possible to exercise economy by introducing air into the building at a temperature substantially below the room temperature and allow the body heat of the occupants, lighting equipment, etc., to provide the balance of the heat required, for the cooler air will inevitably " bore " through the warmer air of the room and complaints of draught will follow. For perfect diffusion of the air, the supply should be within 1 or 2 degrees of the room temperature.

Again, buildings equipped with mechanical ventilation plant are normally occupied during the " peak load " period, and no advantage accrues from the operation of the plant at times other than during the normal occupancy of the building, so that the possibility of obtaining supplies of energy at prices that are directly comparable with coke, coal, or oil, for the direct application of the heat, by means of resistance-type heaters located in the ducts, appears to be rather remote. Notwithstanding this fact, there are of course many cases where the convenience or space factor is the governing condition. An example is the News Theatre in Piccadilly Circus, where an air supply of 4 750 cub. ft. per min. is warmed by a 50-kW resistance-type heater.

Conversely, there are distinct possibilities of econo-

mically employing the thermal-storage system to supply the heat required in those areas of supply where rates can be offered on the lines discussed in an earlier part of the paper, for the period of occupation of many buildings such as assembly halls, offices, etc., is not unduly long and the water storage required is not necessarily excessive. Cinema theatres form the principal exception to this rule, but a solution even for this type of building is not beyond the bounds of possibility, given close co-ordination between the supply authority and the consumer and an efficient system of remote control of the load from the supply authority's control room. Peak periods seldom persist for more than two or three hours and if a two- or three-hour recovery period can be guaranteed between morning and evening the problem does not appear to be insoluble. It is understood that one such installation is already working very satisfactorily in the North of England.

Steam is in favour for air heaters, and where water is employed the mean temperature used is normally 160° or 170° F., but it is quite possible to work at lower temperatures and thereby to reduce the quantity of the water storage required, without unduly increasing the cost of the installation, the size of the heater, or the resistance to the air flow, as Table 28 indicates.

TABLE 28.

Data for Water-Type Air Heaters for Various Mean Temperatures.

Mean water temperature	Cubic feet of air per minute: 10 000			Cubic feet of air per minute: 20 000		
	Resistance (inches of water gauge)	Duct size	Price	Resistance (inches of water gauge)	Duct size	Price
° F.		in.			in.	
170	0·28	42 × 42	£22	0·28	54 × 66	£39 10s.
130	0·25	48 × 54	£30	0·25	75 × 75	£59
110	0·28	42 × 48	£32	0·28	66 × 66	£64

Where it is desired to work at the higher temperature and the temperature of the water returning to the cylinder is 150° F., the low-temperature invisible ceiling-panel warming system can be designed to utilize the water, as the normal flow temperature of the system is from 100° F. to 120° F. in severe weather and from 85° F. to 100° F. in mild weather. In several buildings the ceiling-panel system is operating in series with an older radiator system.

Typical examples of combined warming and ventilating plant operating on the thermal-storage system exist at the West London Synagogue, the Manchester Reference Library, the new headquarters of the Royal Institute of British Architects, and at several other buildings.

(4) COOLING OF BUILDINGS IN SUMMER.

Buildings are now cooled in summer either by cooling and de-humidifying the air supplied by the air-conditioning plant, or by circulating specially cooled water through the invisible panel-warming installation which then operates as a panel cooling system by the absorption of radiant heat from the occupants, walls, floor, and furniture. Both methods involve the installation of powerful refrigerating plant (a 265-b.h.p. motor is installed at the Masonic Peace Memorial Building, London), and there is undoubtedly a very substantial summer motor load to be obtained if attractive rates can be offered for the supply of energy.

Each installation is specially designed for the building and for the given conditions, so that it is not possible to give, in a paper of this general character, data which could be widely used.

(5) TEMPERATURE CONTROL OF AIR-CONDITIONING PLANT.

As in all other types of electric warming equipment associated with buildings, the temperature control of the air supply and the humidifiers should be of the automatic type in order to secure the maximum possible economy. With a mean temperature-rise of 65° F.–44° F. or 21 deg. F. for the season, a variation of only 1 deg. F. represents 4·75 per cent on the energy consumption, and, as has been shown, this may represent very substantial cash values.

Immersion-type thermostats are employed to control the operating temperature of the humidifiers, but the heaters may be controlled in banks, or, preferably, the temperature of the water flowing through the heaters is controlled by means of duct thermostats which, in turn, control one of the forms of water-mixing devices described in an earlier section.

ACKNOWLEDGMENTS.

The thanks of the authors are tendered to the directors of Messrs. Richard Crittall and Co., Ltd., for their kind permission to publish the technical information which has been collected during the design, erection, and testing, of thermal-storage, electric water-heating, and air-conditioning plant in various parts of the country and on the Continent; also to their colleagues, Messrs. Mount Laird, Harrison, Lewis, and Byles, for assistance in preparing the various graphs and tables, and to the manufacturers, including Archibald Low & Sons, Ltd., Bastian & Allen, Ltd., British Arca Regulators Ltd., Ferranti, Ltd., General Electric Co., Ltd., Magnetic

Valve Co., Ltd., A. Reyrolle & Co. Ltd., Siemens-Schuckert (Great Britain), Ltd., and Sulzer Bros. (London), Ltd., for information, data, and illustrations.

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DISCUSSION BEFORE THE INSTITUTION, 6TH DECEMBER, 1934

Dr. Ezer Griffiths: To me, a particularly interesting feature of the paper is the attention given to the question of heat insulation. The authors give data to illustrate the advantages of insulating the ceiling of a house. I think it would be well worth while going into the question of the insulation of the entire fabric of the building. As the authors mention, the possibility of planning a building without the necessity of considering a boiler chimney and such-like adjuncts is of considerable advantage. Furthermore, the ease of control possible with electrical heating justifies greater consideration being given to estimating the heating requirements of a building. It is obviously desirable to economize in the use of electrical energy by taking every precaution to reduce heat loss.

I suggest that the authors amplify the list of materials given on page 463, where they mention granulated and slab cork, slag wool, moler bricks, diatomite, and magnesia. Reference should be made to recent developments in the production of building materials having a cellular structure. For example, cement blocks can be made with a honeycomb structure of a weight per cub. ft. as low as 15 lb. In one process this is effected by the admixture of a foam-producing liquid just before the mix is poured; in another, aluminium powder is added, which reacts with the alkali in the cement to produce hydrogen bubbles, and these result in small cavities being left in the cement. The insulating value of such materials depends on the ratio that the volume of the air cells bears to the solid material. The lighter the material the better the insulator, but of course the mechanical strength falls off as the density decreases. Hence in practice a balance is struck between the relative importance of thermal insulation* and structural properties, unless the material is not required to withstand stress. If the designs of buildings of the type considered by the authors were studied from the point of view of reducing heat leakage to a minimum, then the experience gained in cold-storage construction* might prove helpful in suggesting directions for improvement.

The authors revert to the subject of insulation when considering thermal-storage vessels. It would be helpful if they included a table of the conductivity data used in preparing Fig. 24, and quoted authorities. The information given by the graphs needs qualification such as the density of packing and the diameter of the vessel to which it is applied. Information as to the materials used for lagging hot-water pipes will be found in a paper by Mr. C. Jakeman.†

The authors only briefly touch on the question of air-conditioning, which is becoming an important one, particularly in the case of picture galleries, libraries, and museums, where reasonable constancy of humidity is desirable for the preservation of pictures and other objects of art.

Dealing with the question of refrigeration, the authors refer on page 505 to the circulation of cooled water through the invisible panel-warming installation. What precautions are taken to avoid bringing the temperature of the surface down below the dew point? If this happens the surface will become coated with water.

Dr. O. Faber: The paper begins by asserting "that the commercial practicability of electric space-, air-, and water-heating, has been satisfactorily established." I agree that electric heating is a perfectly practicable thing, and in some places it is a perfectly desirable and proper thing; but the paper is written rather with the implication that even for very large buildings, where one simply wants heat at a reasonable cost, the electrical solution is generally the correct one. If so, I think, the authors' assertion is not always correct. The basic fact is that with coal or coke at 26s. 8d. per ton a therm is

* See EZER GRIFFITHS: "Thermal Insulation," *Journal of the Royal Society of Arts*, 1933, vol. 81, pp. 911, 930, 945; also "Thermal Conductivities of Walls, Concretes, and Plasters," Building Research Board, Technical Paper No. 6.

* E. A. GRIFFITHS: "Pre-cooling Facilities for the Fruit Export Trade," *The Structural Engineer*, 1932, vol. 10, p. 138.

† "The Testing of Steam Pipe Heat Insulating Materials," *Engineering*, 1934, vol. 137, pp. 1, 58, 171, 252.

produced for 1·2d., whereas with electricity at ½d. per unit it is produced for 14·6d.; even with electricity at ¼d. per unit a therm costs 7·3d., which is still 4 to 6 times as much as the cost of heat produced from coke. The reason for this position is that electricity is produced in generating stations where, for reasons which we all quite well understand, the overall thermal efficiency is about 25 per cent; and in addition there is the enormous cost of plant, mains, etc., to be taken into account. No one is blaming the electrical engineer for this state of affairs, but some people may feel disposed to wonder why he will not recognize the facts.

At the bottom of page 462 the authors refer to heat supplied electrically as "high-grade" heat and also as "purified heat." I should like to ask how the heat given out by a hot-water radiator which is fed from an electrical thermal system differs from the heat given out by a hot-water radiator which is fed from a boiler fired with coal, coke, or oil. In many places in the paper we are referred to the fact that an electrical heating system has no losses and that a hot-water radiator system has many losses; but the thermal-storage electrical heating system has the same loss on its hot-water mains as the ordinary central-heating hot-water system. The only difference is that in the case of the electrical system the heater in the boiler takes the place of the oil burner or any alternative fuel. I think it would be helpful if the authors differentiated more closely between the thermal-storage systems and the systems of direct electrical heating. While systems of direct electrical heating eliminate certain losses, such as those from hot-water mains, they involve, unfortunately, paying a higher price for the electricity.

On page 464 my name is quoted in connection with some figures for the total weights which had to be carried on the foundations of certain buildings. The authors use these figures for the purpose of calculating how much heat is required to raise the temperature of those buildings, and they eventually arrive at the conclusion (page 464) "that the heat required to raise the temperature of the structure through 1 deg. F. is some 4·34 times the heat required per hour to maintain the temperature of the structure when the outdoor temperature is at freezing point." Their calculation is based on a fallacy. To raise the temperature of a building through 1 deg. F., one does not raise the temperature of the foundations or of the outside walls right through their thickness. Correcting the authors' figures for these various matters, the value obtained is much nearer 1 than 4·34. Even if it were 1, however, the conclusion which the authors come to is that to raise the temperature through 1 deg. F. requires as much heat as is required to maintain the temperature of the building for an hour; consequently, to raise the temperature 10 deg. F. would require nearly 10 hours, even if the heating plant were made twice as big as is required just to maintain the temperature, and if the authors' figures were right it would take nearly 43·4 hours—a terribly long time. This all goes to show that the capacity of a heating plant has to be very much greater than that required to maintain the temperature in a building. The extraordinary thing is that nearly all electrical engineers, when they approach this problem, are at great pains to show that the amount of heat which they are going to supply to a building is very much less than that which coke or oil or coal is going to supply, and that electricity makes it possible to employ a much smaller number of B.Th.U. Yet the authors on page 464 give the strongest possible argument why the heating capacity should have a very large margin, in order to be able to keep pace with the rise and fall of conditions. I should very much like to know why later in the paper the authors entirely ignore the conclusions which they themselves have put forward on page 464.

It does seem to me that unless we can reconcile a little more closely the cost of the electrical therm to the cost of the therm produced in other ways, we shall not find ourselves so near the era of general electric heating in our biggest structures as we should like to be. The figures given on page 468 are intended to compare the costs of electricity, oil, and coke. As regards the table given in Fig. 4, it is quite hopeless, I think, to discuss this problem on the basis of efficiencies of 12 and 18 per cent respectively for coke-fired and oil-fired central-heating installations; in actual fact these values are enormously higher. The figure of 35 per cent for the efficiency of the system, I presume, is intended to allow for the radiation losses on the mains. I know of no other losses, once the losses on the boiler have been taken into consideration; and all the losses contained in this figure of 35 per cent apply just as much to the electrical thermal-storage system. Therefore, I do not see how any calculations based on figures of this kind can take us very far.

Mr. L. C. Grant: It is interesting to recall Dr. Ferranti's remarks* at the discussion on the papers by Col. Monkhouse and myself, and Mr. Haldane, which were read before the Institution 5 years ago. He stated that he thought the future of electrical development depended on electric heating, and advocated the storage of electrical energy in hot water. The first electrical storage installation in this country was carried out by Gatti at the Vaudeville Theatre, about 10 years ago. The next installation, with which I was myself concerned, was a 250-kW electrode boiler working at 6 000 volts. That engendered a considerable amount of concern with the Post Office, and other people. I was told by the insurance company that the boiler did not conform to standard marine boiler practice: it embodied too much welding; while the Post Office were apprehensive about harmonic currents circulating between the boiler and the power house. Nevertheless, the tests went through quite satisfactorily and the boiler stayed in service. At that time electrode boilers were under suspicion, and in order to find out the Continental view I made a tour of several countries. Rather to my surprise, I found that Continental users regarded electrode boilers at voltages up to 33 000 volts in a more phlegmatic way than our quite small boilers had been regarded here up to that time. As a result the Carliol House and other schemes went ahead.

All the bogies of the subject seem now to have been laid. One of the most promising applications of electric boilers is for industrial use—not necessarily for central heating, but to provide steam for process work, especially in small plants. I have recently installed a 250-kW

* *Journal I.E.E.*, 1930, vol. 68, p. 676.

3-phase boiler in Liverpool; that boiler is running for 22 hours per day, and, through the helpful collaboration of Mr. P. J. Robinson, the city electrical engineer, a tariff has been obtained which should greatly alter the outlook of not only industrial installations but also heating installations. The boiler is being supplied with current at what is commonly regarded as a thermal-storage rate for current, and operates continuously except for the evening-peak period between 4 and 6 p.m. That, coupled with the fact that in buildings there is considerable inherent storage capacity which, in our nervousness, we have not utilized, makes me think that electrical heating will in the near future be done without storage tanks. I carried out some tests on a building of 2 000 000 cub. ft. capacity about a year ago. The heat was cut off at 3 p.m. and switched on again at 3 a.m. Recording thermometers placed in various rooms showed that at no time did the temperature fall more than 3 deg. F. Generally it fell only 1 deg. F. That eliminates 75 per cent of the storage capacity, and with very little manipulation the remainder could, I think, also be eliminated. Whether this is possible or not, we still have the methods of supply which the Central Electricity Board are making available for us. The peak-hour limitations imposed by the Board tariff operate between 7 and 9 o'clock in the morning and 4 and 6 o'clock in the evening. For electric heating this is very helpful, and it will enable us in the very near future to run electric boilers during the daytime and evening, avoiding only the two 2-hour peak periods, and thus eliminating storage. This will halve the cost of the plant for the heating system, and will considerably reduce the space required.

The authors refer to swimming pools, and to the heating of buildings by means of the heat pump. The heat pump gives an exceedingly high efficiency. It is, roughly, an inverted refrigerating machine, and over practicable ranges of temperatures has been shown to have an efficiency of 2 or 3. An important point to remember in this connection is that the same plant will do for cooling the building in summer and for operating the air-conditioning plant, either at the same time as the heating apparatus or while the cooling plant is operating during the summer time. Thus we have a sort of triple-value boiler house with an efficiency of what may seem a startling value. I submit that the heat-pump system is very promising and ought to be followed up. Mr. Haldane a few years ago built a small heat-pump plant and operated it in London very successfully. I think it was afterwards transferred to the North and that there it is still in operation. In Detroit and one or two other American cities heat-pump heating installations of considerable capacity have been installed. I notice, too, that the American papers in advocating this scheme give full credit to the English engineers who developed the idea. It is rather disappointing that we ourselves have not developed it appreciably. On this type of heating there is a temperature limitation. If a very high temperature is required its advantageous efficiency grows less and then vanishes; but for swimming pools, where the temperature range required is small and where the top temperature is not very high, efficiencies even higher than 2 or 3 can be obtained. For a swimming pool an efficiency of about 5 can be obtained with very little trouble.

I think the control gear for electrical thermal storage is becoming too complicated and is achieving a reputation for unreliability. We ought to try to keep thermal-storage apparatus as simple as possible.

Mr. J. R. Cowie: I should like my mains-engineer friends to take 1 square mile of any large city and find what the loads are, and what loadings of 2 000 kW and upwards per building would lead them to in the distribution networks. It will, I think, be necessary to transmit at 66 000 or 132 000 volts to central points. The authors point to this by saying that 0·5-sq. in. 410-volt cables are no longer of any use; they recommend 11 000-volt supplies for the apparatus of to-day. I suggest that we shall have to consider the possibility of 22 000-volt supplies, because 11 000-volt supplies will not take us very far on these big building loads.

I now come to the question raised by Mr. Grant, of longer unrestricted hours. The effect of that suggestion is to cut down the kW size of the plant and to reduce the storage capacity. It does not quite keep clear of the station load curves, because those curves are individual to each system; but those curves are not affected quite so much as many people think. Turning to tariffs, the authors indicate that the figures mentioned in the paper are not very common. That is entirely wrong. Figures of 500 units per £ are quite commonly given for a day load, and much better figures for a 24-hour load. Figures of 1 000 units per £ are very common. Further, figures such as 1 200 to 1 400 units per £ have been in operation for quite a number of years. The effect of the heating load is to lower the price of the unit, and to lower the incidence of kW charges.

I now turn to some of the figures given by the authors, and, although I understand the basis which the authors have used, I am going purposely to turn them round in order to paint a different picture. Let me take page 465, Section 5, and the top of page 466: 180 kW is 614 800 B.Th.U. per hour, and 240 kW is 819 640 B.Th.U. per hour. In both cases the whole of the apparatus is in the same rooms, and has exactly the same type of control. What has happened to all the lost B.Th.U.? Have they gone out of the building, or are they still in the rooms, or are they represented by the difference in the efficiency of 25 per cent, which the authors mention on page 464? Incidentally, this figure of 25 per cent is not borne out by the values 300 and 400 kW given on page 466, the difference between which is not 25 per cent but 33⅓ per cent. I find, on looking into the figures, that they are worked out in some instances on a basis of 24 hours and in other instances on a basis of 12 hours; and they do not always appear to be worked to the same temperatures. If I am correct, they are not comparable. With regard to the system of ceiling heating, the temperature is given in one part of the paper as 100° F. (for structural reasons), while for another special form it is given as 200° F. In some quarters ceiling heating is unpopular because certain people, especially young children, quickly feel ill as the result of heat radiation striking down on to the head. Again, physical discomfort in the lower extremities takes place, partly because the heat is not striking low enough down

and partly owing to the incidence of cold air at a lower level. Better results are being obtained with panel heating in the walls, and even, in some instances (although the structural difficulties are great), in the floor; combined with some form of dull heating such as tubular heating and/or water heating. The most pleasant effect of all, however, is the one mentioned by the authors where low-temperature (50–56° F.) water is used, reinforced with radiant heat. Experiments on radiant heat show that, even with the most efficient radiators, the angle of heat dispersion is not flat enough. They could, for this particular class of work, be altered in design, but some of the panel luminous heating work is extremely pretty and artistic, and it gives very pleasant physical results.

I should now like to give particulars of one or two actual heating installations. The first is that of a garage; heated continuously, with a loading of about 300 kW, it shows a consumption per cub. ft. per annum of 0·89 unit. Other garages, heated only through the night, with a loading of approximately 1 000 kW, give the figure 0·54 unit per cub. ft. per annum. Omnibus garages generally have an inside temperature of about 54° F., and the average external temperature is about 42° F. My next example, a one-story factory with heavy leakage through the roof, shows 0·94 unit per cub. ft. with a loading of approximately 300 kW. The following figures are for some big buildings of the office class, purposely chosen because of their large radiating surfaces or their cold situations: 0·75 unit per cub. ft., loading about 1 000 kW. For a similar group of small buildings the figures are 90 kW, 90 kW, and 120 kW, and the consumptions 1 unit per cub. ft., 0·98 unit per cub. ft., and about 1·05 unit per cub. ft. respectively. Over a very wide range of application, covering hot-air systems, panel systems, and radiator systems, the figures range from 0·754 to 1·035 units per cub. ft.

Turning to swimming-bath heating, we often find that absurd figures of the loss per day are put before us, thereby immediately loading the case against electricity when an existing heating equipment is being compared with an electrical installation. The figures of an indoor swimming-bath, where the room temperature is 56° F. and the water temperature about 73° F., show that on a summer day the loss of temperature is 0·5 deg. F., and on a winter day 1·5 deg. F. The figures become better if the swimming pool is of large capacity. As regards outdoor swimming-baths, these are used for 26 weeks compared with the 52 weeks of indoor baths. I have in mind an outdoor swimming-bath where the water temperature is 74° F. The loss per day varies between 2·75 deg. F. on a good day, to 4 deg. F. on a bad day. In both the indoor and the outdoor swimming-bath the consumption per gallon per annum is 1·8 units. It is known that the outdoor bath can, in regard to its chemical plant, stand further improvement and adjustment, and that the final figures will be rather better than those I am quoting now.

Dealing with the costs of electrical heating as compared with those of the coal-fired boiler which has been dispensed with, the saving in cost is 17 per cent, and will be higher when slight improvements have been made. Figures commonly given to me for outdoor swimming-bath work are no less than 6–8 deg. F., and for indoor work 3–4 deg. F.—much too high. I now turn to some of the authors' figures. The average annual consumption of the building considered on page 464 works out at 0·172 watt per cub. ft., and the authors' figure for the estimated loss is 0·45 watt per cub. ft. That shows a seasonal factor for the building of 39 per cent. The figure given by the British Electrical Development Association is 40 per cent. When I turn to Section (7), I find that the authors use factors of 57·5 per cent in the electrical case and 66 per cent in the coke case, where the E.D.A. figure would have been 60.

Turning to page 471, where the heating of "flats" is considered, there is in use in our colonies a load-limiting device which, when the heating load exceeds a predetermined amount, switches off the heating load but maintains the lighting. When the heating load has been reduced, the device switches in again. It should have a useful function in the particular case considered by the authors.

Lastly, I turn to the subject of protection, which forms the most important section of the paper. The paper mentions the difficulties of the immersion type of apparatus. If a fault occurs at the extreme end of the coil down to the tube there is a danger of burning through the tube. The only cure is robust metal in these container tubes and an adequate design of the bobbins, because that class of fault would not be removed if 15-ampere fuses were fitted to every one of the immersion-heater tubes. That, and lower efficiency, are the two disadvantages of this particular method of heating. It can be got over—and not expensively, as the authors would rather indicate—by using the current transformers which are added to the contactor for ammeter service in any case, and putting thereon earth-leakage protection of the instantaneous type, having settings of 5, 10, or 15 per cent. That earth-leakage protection will remove a 15-ampere fault, because the fault is generally of an arcing-earth nature; and it will certainly definitely remove the section if one of these elements is open-circuited. The same class of protection can be much more easily used and added to low-tension electrode boilers. The real difficulty—the protection of the high-tension electrode boiler—is not dealt with in the paper, but it is a very big subject. Insulating of the water main from the electrode boiler is of no use, because the loaded and heated water has far too high a conductivity. The whole pipe system must be connected solid and precautions taken in accordance with the I.E.E. Wiring Regulations. Care must be taken that the resistance between the earth plate and earth is 1 ohm, or preferably less. My suggestion for protection on the boiler itself (where there are already current transformers for overload protection, ammeters, etc.) is to add earth-leakage protection, preferably the induction type. There is some slight time-delay, and that time-delay is of advantage because it will take account, to a small extent, of the direction of flow of the earth-fault currents. If earth-leakage protection is installed on the external feeders of the system they also must have relays of this type, otherwise sections of the feeder network will trip out. Overload protection, properly designed, will not be affected owing to the presence of

electrode boilers; nor will discriminating protection be affected. I recommend that every earth-leakage device should be removed from the network and placed on the apparatus. If this cannot be done, and there are many earth-leakage devices, directional features must be employed.

Mr. W. R. Cox: The figures on page 463 relating to the effects of insulating the whole of buildings are very striking. The authors devote most attention to ceilings. I should like to point out that modern buildings, especially factories and offices, are designed with very large window spaces in the walls, which must be the cause of considerable loss of heat. Would it not be practicable to reduce this loss by paying attention to the insulation of window spaces?

Turning to the question of ventilation, the provision of warmed air is expensive but at the same time very important. Nearly everybody favours open fires in sitting-rooms, chiefly because of the good ventilation resulting. I think it must also be admitted that all but a few of the newest public buildings, office blocks, etc., are insufficiently ventilated. This is no doubt largely due to considerations of expense, but a reduction could be effected if the ventilating system were designed to be partly regenerative, by extracting some of the heat from the foul air expelled from the building. This would probably be easier in theatres, cinemas, and halls, where the passage of air through the building is fairly well defined, but should also be possible in nearly all buildings if the air flow through the building were properly arranged for in the early stages of the design. Such a building would probably have its windows permanently closed. Besides cheapening this part of the building, such a system of ventilation would have the incidental advantage of greatly reducing the amount of street noise penetrating into the building.

The authors give a very interesting number of illustrations of the various types of electrode boilers and water heaters now on the market. This type of apparatus is very simple and efficient, also maintenance costs are very low, and a much more general adoption will no doubt follow. The fact that high-voltage supplies can be used for units of approximately 500 kW and over eliminates transformers and the great multiplication of small units which is necessary with immersion heaters. The electrode heater appeals as a much better engineering job for the larger units. One of the difficulties in the application of electrode boilers is the surprising variations one finds in the resistance of ordinary town water supplies. As is pointed out by the authors, these variations are inherent, and due to salts and impurities dissolved in the water. The following formula may be of service: $R = 750\,000/A$, where R = specific resistance at 15° C., in ohms per cm^3; and A = total solids, in milligrammes per litre, after evaporating at 100° C. This formula gives quite good results if there is not too much lime or sodium chloride present. Boilers and water heaters must be designed to a large extent to suit the water to be used in them, but this, generally speaking, presents few difficulties. As pointed out in the paper, an electrode water heater provides a solid earth to the distribution system, but present-day practice is tending towards multiple-earthed systems and this feature is likely to prove popular. It must also be remembered that steam boilers can easily be built with insulated neutrals, and are used to a considerable extent in some parts of the Continent.

The authors refer to air-break circuit breakers, and state that 600 amps. at 400 volts can easily and satisfactorily be dealt with. This type of apparatus has been designed for very much more arduous duty in rolling-mill equipments and on board ship, on circuits of 300 and 400 amps. at 3 300 and 6 600 volts. This seems to indicate that any ordinary heating circuit can, if necessary, be controlled by air-break circuit breakers.

In the list of insulating materials given on page 490, reference is made to aluminium foil. This seems a very compact type of heat insulator, and one which should find wide application; further information on this type of insulator would be useful.

Col. S. F. Newcombe: I am personally interested in the housing question, and therefore in that part of the paper which applies to the heating of houses. Dr. Faber has criticized the authors' actual figure of 4·34, given on page 464, but the fact remains that an immense building does absorb an enormous amount of heat. Therefore, if we insulate the inside of the wall, we reduce to some extent the heat going into the building. Mr. Dufton, of the Building Research Station, published a year or two ago the fact that he lit his fire in his dining-room at 7.30 a.m., room temperature at 45 F., and was able to have his breakfast at 9 a.m. at a temperature of 60° F. The room had ordinary plaster and brick walls. He then lined the walls with wood, and lit his fire, room temperature also at 45° F., at 8.30 a.m., and had his breakfast at 9 o'clock at 60° F. This experiment shows how quickly a room will get warm if well insulated. Where the heat insulation is poor, it is necessary to heat the walls as well as the room. Mr. Cox referred to aluminium foil, a subject in which I happen to be interested. In an electrical heating system the consumption of heat is dependent, more than in any other form of heating, on quick heating. Therefore a very light material such as aluminium foil in the interior lining of the building will keep out the heat from the wall, and make rapid heating possible.

In this enormous housing programme which we are going in for, no ruling has been given as to what should be the correct air-to-air transmission value of a roof or a wall. That value should surely, with electrical heating, be smaller than with any other form of heating; because it is purely a question of expense paid for insulation as compared with the expense of the unit of heating. I think the Ministry of Health might lay down in their by-laws some guide as to the economic unit of air-to-air transmission for roofs and for walls. It will require a considerable amount of co-operation between the manufacturers of insulating materials, electrical engineers, and heating engineers, to determine where the economic point may be, but the money spent on insulation certainly gives a very high return.

Mr. W. L. Shand: Electricity for domestic water heating already competes successfully with its rivals—coke, coal, oil, and gas—even on the basis of cost. This is because use is made of thermal storage, whereby specially low rates can be quoted. The authors go a

step further and contend that the thermal-storage principle can also be applied to space heating without the intervention of any special storage medium like water, since the heat-storage capacity of the walls and furniture is enough. We electrical engineers believe that where the occupier of offices or domestic premises can afford the amenities of central heating and a constant supply of hot water, however supplied, electricity is the most economical medium, provided always that it is properly applied. It must be recognized, however, that the average householder, his advisers (the architects), and his builders, have the idea rooted in them that electricity is dear compared with the other sources of heat to which they have been accustomed for many years. Thanks to the excellent propaganda work done by the supply undertakings in co-operation with the British Electrical Development Association, however, people are becoming more and more electrically minded, and as soon as they are convinced that the cost is reasonable the battle will be won for electricity. We must, therefore, concentrate on price reduction, and many undertakings are already offering prices so low that they must rely upon diversity to keep them from bankruptcy.

Is not this reliance upon such an uncertain quantity as the "diversity factor" already dangerous, and will not the danger increase as cheap units for so-called off-peak loads are sold in larger and larger quantities? Since most 2-part tariffs are based on a hypothetical lighting maximum demand—translated into terms of floor area, number of rooms, or rateable value—it is of vital importance that water-heating and low-temperature space-heating should be kept off the peak, since the prices per unit which have to be quoted to obtain these loads at all must be so low as to leave little margin for fixed charges. How are we to provide for this? There are undertakings so large and having so many different classes of load, industrial and domestic, that they feel safe to offer a supply unrestricted as to hours of use and incidence of peak, relying solely upon natural diversity, and undoubtedly at present this natural diversity is often remarkably high. Others less courageous—or more provident—adopt time-switch or load-leveller control, or at any rate make it a condition of a lower price to consumers that they can restrict the service if they want to do so. In America it is the practice for supply undertakings, both gas and electric, to charge a householder a fixed contract price per month for keeping his house at a certain temperature throughout the winter, instead of charging for electricity or gas as such. A survey is made of the insulating properties of the building structure before a price is quoted. It must be admitted that an accurate adjustment of price must sometimes be sacrificed to simplicity, because consumers are shy and suspicious, and at the slightest sign of complication they will revert to coke, oil, or gas, the charges for which they understand. Thus if the low-price supply is to be kept off the peak such devices as time switches or load-levellers on consumers' premises must be avoided. We must find some other way of arriving at the same result, namely an approach to 100 per cent load factor, by ensuring that the whole of the thermal-storage load is kept off the peak while at the same time full use can be made of the whole of the off-peak units corresponding to the normal peak. Thus these particular classes of load would incur no fixed charges. If this is done the price quoted to the consumer can be the lowest possible consistent with a proper economic return. I believe that the device which most nearly approaches this ideal is the change-circuit system (invented by Mr. George Wilkinson), which makes use of voltage variation to control the supply to thermal-storage appliances in such a way that while these are automatically kept off the peak they will yet receive so ample a supply of watt-hours that the consumer will be unconscious of any restriction.

Mr. D. J. Bolton (*communicated*): On page 496 is given the daily hot-water consumption of "a family of four people of the normal suburban habits," totalling 100 gallons a day at 100 deg. F. temperature-rise. This figure is an extremely high one. The energy consumption would be over 8 units per day per person, instead of the figure of 2 or thereabouts which is frequently given. A normal domestic tariff for such a purpose will have a secondary rate of $\frac{3}{4}$d. to $\frac{1}{2}$d. per kWh—hardly ever less than the latter figure for unrestricted supplies. Taking the mean of these two, the hot water for the family of four is going to cost £34 a year. If these are "normal suburban habits" they will soon be cured by a dose of electrification! Surely such a case (which fortunately is not normal) had best be met honestly and simply by recommending a coke-fired boiler, with perhaps an immersion heater in the tank for summer use at off-peak prices.

Mr. A. Cunnington (*communicated*): Although the authors have dealt mainly with the larger buildings where a low tariff is available, I am encouraged by the discussion of general considerations in Part I to put forward some suggestions. As an engineer responsible for the heating of buildings on a railway, I am naturally concerned with very varying circumstances, both in regard to heating requirements and in respect of electrical supply. We have to deal with blocks of offices or station buildings dotted about the line, and not necessarily in or even near London or other centres where rates may be low; yet we are anxious to avail ourselves of the advantages of electric heating, especially in view of the fact that we have current necessarily laid on for lighting and power purposes in many cases. It seems probable that some time will elapse before the very low heating rates dealt with in the paper will become generally available, and there seems no reason why we should wait until such rates are common practice.

To meet the interim conditions, it has occurred to me that a combination of a central-heating system having a coke-fired boiler, with thermostatically-controlled electric heaters for the purpose of "topping up" the heating as may be required for the peaks, might be an economical system. This would have the advantage of using the cheap fuel which is readily available on the railway for what may be termed the "foundation" heating of the premises, whereas electricity would be used more or less intermittently for producing comfort conditions, and would, I think, be justified even at a fairly high heating rate. I have in mind anything

from a $\frac{1}{2}$d. to $\frac{3}{4}$d. per unit. It has always seemed to me unfortunate that central-heating installations have to be designed with a capacity for dealing with a high temperature-rise, which will often only occur two or three times in a winter and only for a few days. All the rest of the time the capacity of the installation is unnecessarily high, and it appears that an appreciable saving in first cost would be effected by installing a system for dealing permanently with a maximum temperature-rise of something like 15 deg. F. and handling occasional spells of cold weather entirely by auxiliary electrical heating. I notice that the graph in Fig. 9 shows only one period of really cold weather, extending over about 2 weeks, and two small peaks which could not have lasted more than a few days. For all the rest of the heating season the average temperature-rise works out at only 14 deg. F.

I am confirmed to some extent in the idea of the dual system of heating by experience in my own home, where it was found more convenient to install a small central-heating system, only capable of producing a core of heating throughout the house, but supplemented by electric radiators in the living-rooms. It will be noted that there are a good many parts of any premises that do not need to be warmed to a temperature comfortable for sitting, and this is a further argument in favour of "topping up" where required.

I am aware, of course, that the installation costs are likely to be high on such a system, but where electric heating apparatus is installed as part of a general scheme of distribution for lighting and power (which can readily be arranged on any of the modern "all-in" tariffs) the additional cost of the electric heating installation should not greatly exceed the saving effected by installing a much smaller boiler system. There are other incidental advantages, such as a considerable reduction in the number of weeks in the year during which the boiler system would have to be run, seeing that the fringe of the season could be dealt with entirely electrically. Moreover, the necessary margin referred to by the authors in the second paragraph of Section (7), on page 466, would not be required, and the boiler system might be run at a maximum of efficiency. I should appreciate very much the opinion of the authors on the feasibility of a dual system such as this, for use until such time as the cost of electrical energy makes electric heating a matter of course.

Mr. A. L. Fielding (*communicated*): Last February I had before me the problem of whether electric ceiling heating was satisfactory for a new 12-story office block which was to be erected in Sydney for the State Railway Department. The conditions there are somewhat different from those in this country. For example, the heating season extends from the end of May to the end of August, a total of approximately 90 days only, whilst the average temperature throughout the year varies from 55° F. to 75° F. approximately. The cost of electricity to the Department was 0·4d. per unit.

I made extensive inquiries, but could find no installation of a similar magnitude. I should be interested to learn whether one exists. I refer, of course, to direct electric ceiling heating as covered by Part II of the paper. As a result of my investigation, however, I came to the conclusion that such a system of heating was technically and economically sound, but that in certain rooms a judicious addition of other forms of heaters—such as the tubular type, or wall panels—was advisable.

Equally important is the question of the most suitable type of temperature control. For individual room control there appear to be three types of thermostats to choose from: (1) The straight bimetal strip type with air-break contacts. (2) The coiled bimetal strip type operating a mercury switch. (3) The gas-filled bellows type, also operating a mercury switch. I should be glad to know which type is favoured for an a.c. circuit by the authors, what operating temperature differential is desirable, and whether this is attained. Furthermore, does this increase with age, and to what extent?

Mr. T. G. N. Haldane (*communicated*): I wish to deal exclusively with only one section of the paper—that on page 502 dealing with the heating of swimming pools. No reference is made here to the possibilities of using the heat pump, although one at least of the authors is, I think, aware of its peculiar suitability for such purposes. The great possibilities of this method of heating swimming baths were emphasized in a paper dealing with the heat pump* read before the Institution in 1929, in which it was pointed out that "efficiencies" or coefficients of performance of between 5 and 7 might reasonably be expected; in other words, the consumption of electricity would be between one-fifth and one-seventh of that necessary with direct electric heating. Since this paper was read one well-known manufacturer of refrigerating plant has, in tendering for heat-pump equipment for swimming-bath purposes, repeatedly guaranteed efficiencies of the above order of magnitude. The fact that no heat-pump plant has yet been installed for swimming-bath heating is due principally to three causes; first, the fact that most of the swimming baths for which the scheme has been considered would only operate for 6 months or less in the year, and are therefore less suitable for a plant whose operating cost is low but whose capital cost is high; second, that the plant is novel and that its possibilities are not as yet very widely known, despite the research and development which have taken place in the United States; third, there is no patent associated with the heat pump, and consequently there has not been sufficient direct financial interest involved to permit the necessary expenditure on publicity and development. In Great Britain there is only one commercial installation of a heat pump, that at the Fylde Ice Co.'s works at Fleetwood, where the plant is used for the production of warm water for thawing-out ice cans. A good deal of interest has, however, been shown in the subject recently in this country, largely as a result of developments now taking place in America.

In dealing with swimming-bath heating the authors of the present paper refer to the Empire Swimming Pool at Wembley, which is electrically heated by means of two electrode boilers. I think that if they had considered the possibilities of the heat pump they would have realized that in this particular instance the case for the heat pump is almost overwhelming, because the necessary plant is in fact already installed. The Wem-

* *Journal I.E.E.*, 1930, vol. 68, p. 666.

bley bath is used as a swimming pool only during the summer months; during the winter season it is covered over and used as an artificial ice rink. For this purpose

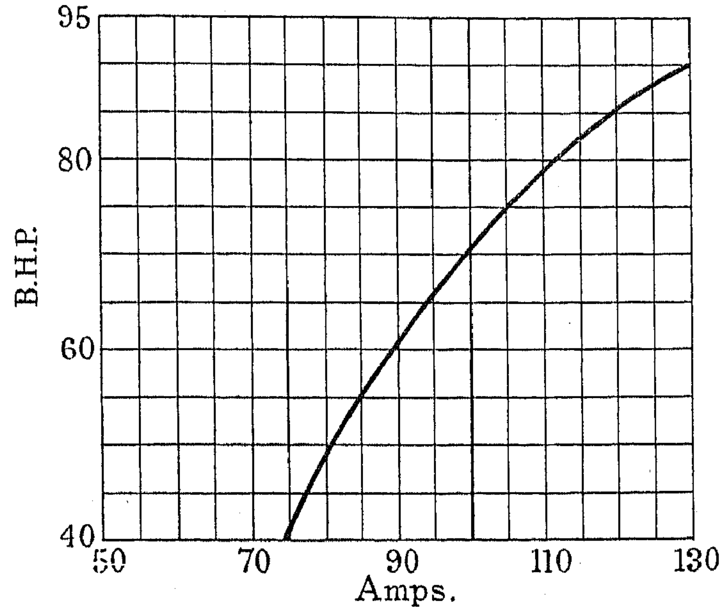


FIG. A.—Performance characteristic of induction motor for driving ammonia compressor.

two ammonia compressors have been installed, and condensing water is drawn from the neighbouring lake. One of these machines alone would be quite sufficient to do the necessary heating of the swimming bath, since the mains would therefore be the equivalent of about 455 kW of direct heating. The total contents of the bath are 650 000 gallons, and, taking the daily loss of temperature as being 2·5 deg. F., the total heat input required to maintain the temperature constant is 16·25 million B.Th.U. per day. This quantity of heat could

TABLE A.

Performance Data of 90-h.p. 415-r.p.m. 415-volt 3-phase 50-cycle Induction Motor for Driving Ammonia Compressor.

Load	Current	Power	Power factor	Efficiency
	amps.	b.h.p.		Per cent
Full	129	90	0·81	90
Half	97	67·5	0·79	91
Half	77	45	0·68	90
Zero	52	—	—	—

be delivered by one of the existing machines operating for a period of about 10½ hours a day, which would come within the off-peak period. Complete information as to the guaranteed performance characteristics of one of the compressors at Wembley is given in Table A and by the curves in Figs. A, B, and C. As already mentioned, the case for the use of the heat pump at

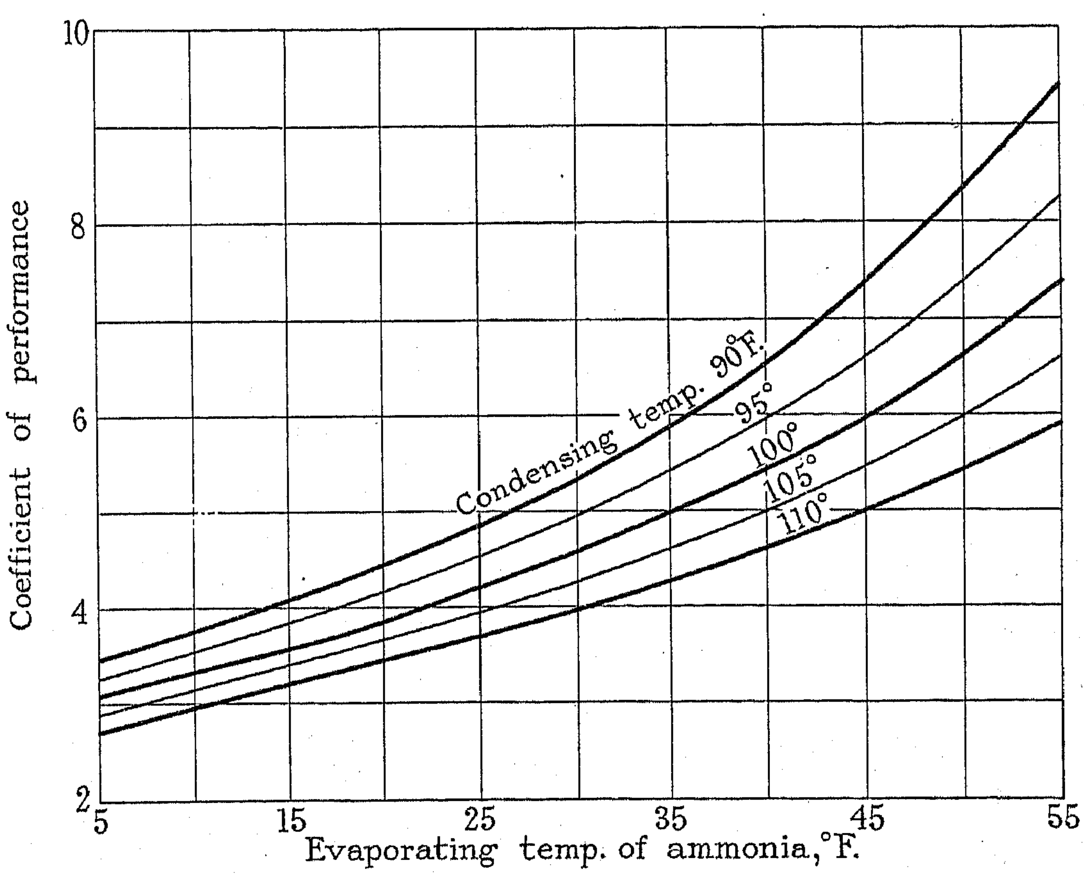


FIG. B.—Performance characteristic of ammonia compressor (capacity 238 cub. ft. per min.).

$$\text{Coefficient of performance} = \frac{\text{Heat output}}{\text{kW} \times 3\,413}$$

the average temperature of the lake during the summer is at least 50° F., and when heat is drawn from this source and delivered to the swimming-bath water, whose temperature is about 72° F., the efficiency or coefficient of performance will be approximately 6·5. The output of one machine taking about 70 kW from Wembley seems to be overwhelming, since all that is required is a small alteration to pipework and the possible addition of a little extra condenser and evaporator surface. The economy which would be effected, assuming current at ½d. per unit, would be about £1 000 per annum for a 6 months' season.

Although the Wembley instance is peculiarly favourable, it does seem desirable that any authority or company installing a swimming bath, particularly if it is to be used all the year round or if it is proposed to heat it electrically, should investigate the possibility of the heat pump.

Mr. A. C. Pallot (*communicated*): Dr. Griffiths has mentioned that work is being done in connection with air-conditioning in picture galleries and museums; in this connection the results of an installation in the Lower Orangery at Hampton Court Palace may be of interest. The plant was designed by Mr. J. Macintyre, of H.M. Office of Works.

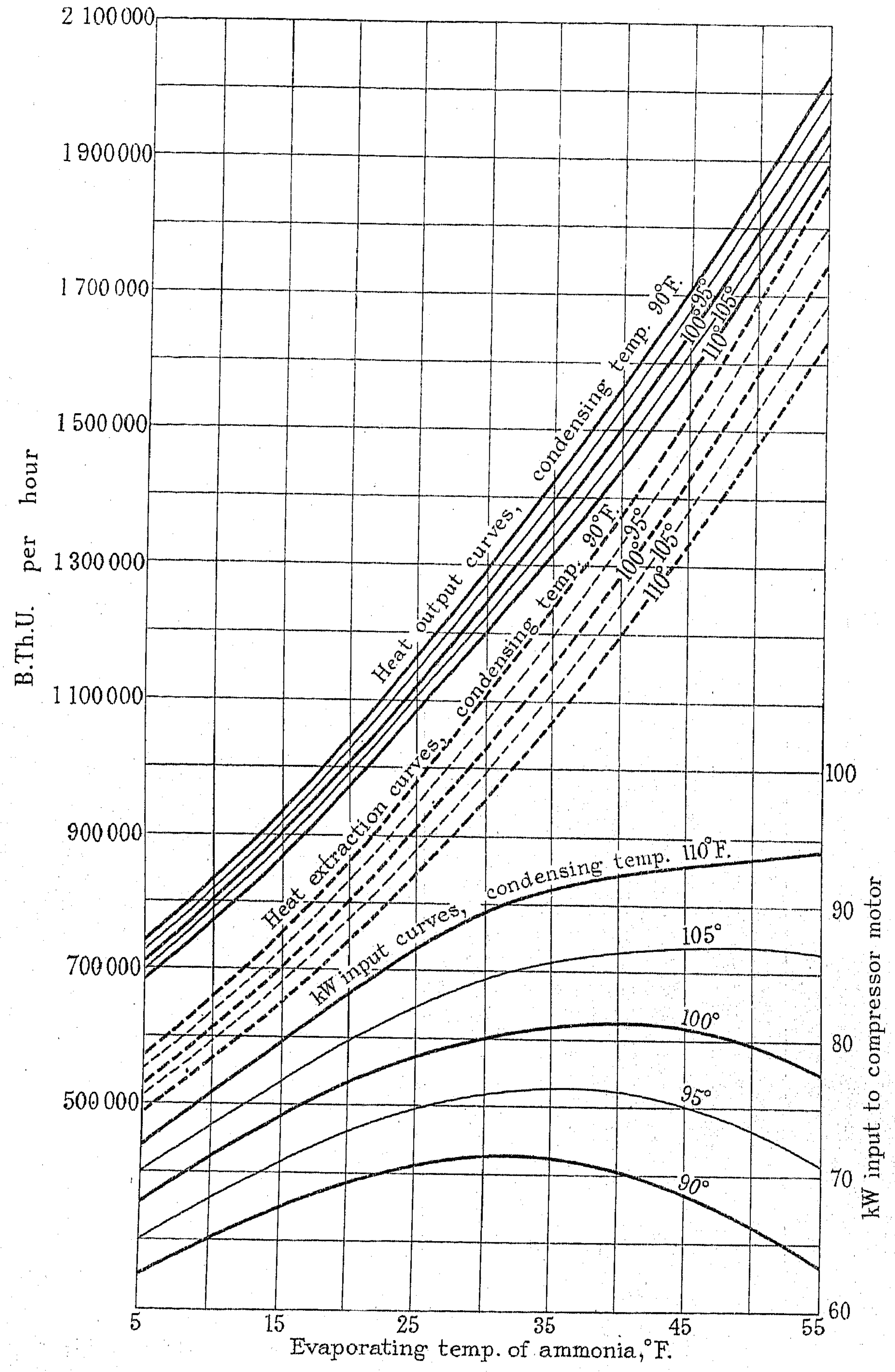


FIG. C.—Heat extraction and output, and power input, characteristics of ammonia compressor (capacity 238 cub. ft. per min.).

In the Orangery the Mantegna Cartoons are exhibited and, from the point of view of preservation, an undertaking was given that the relative humidity within the

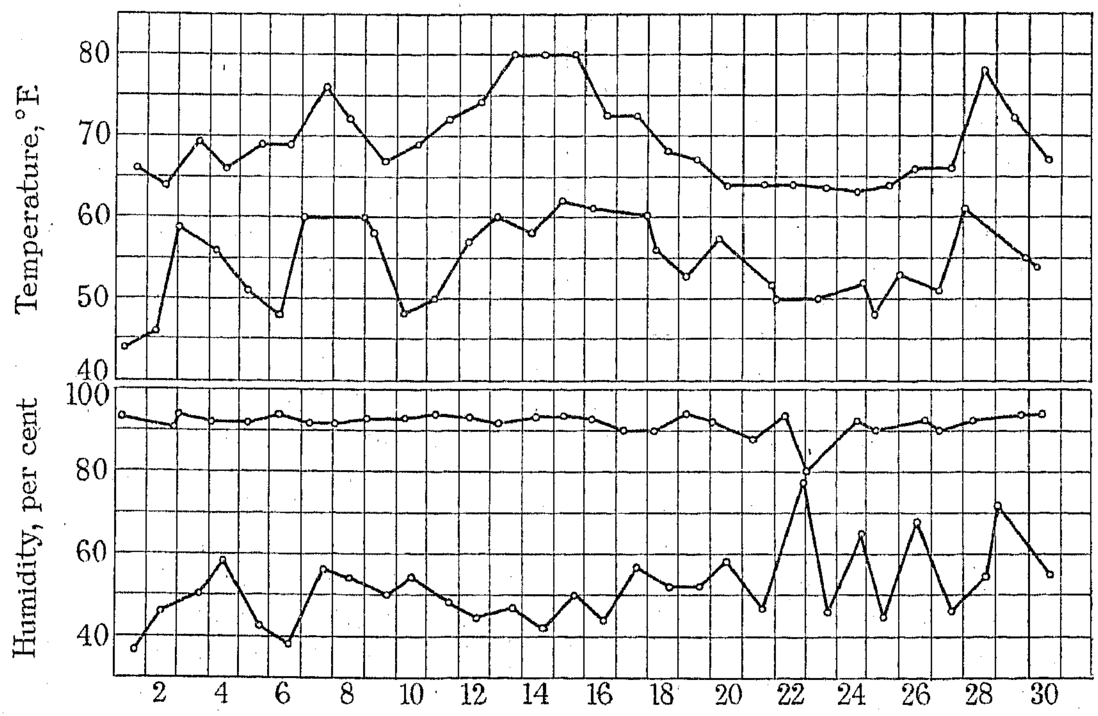


FIG. D.

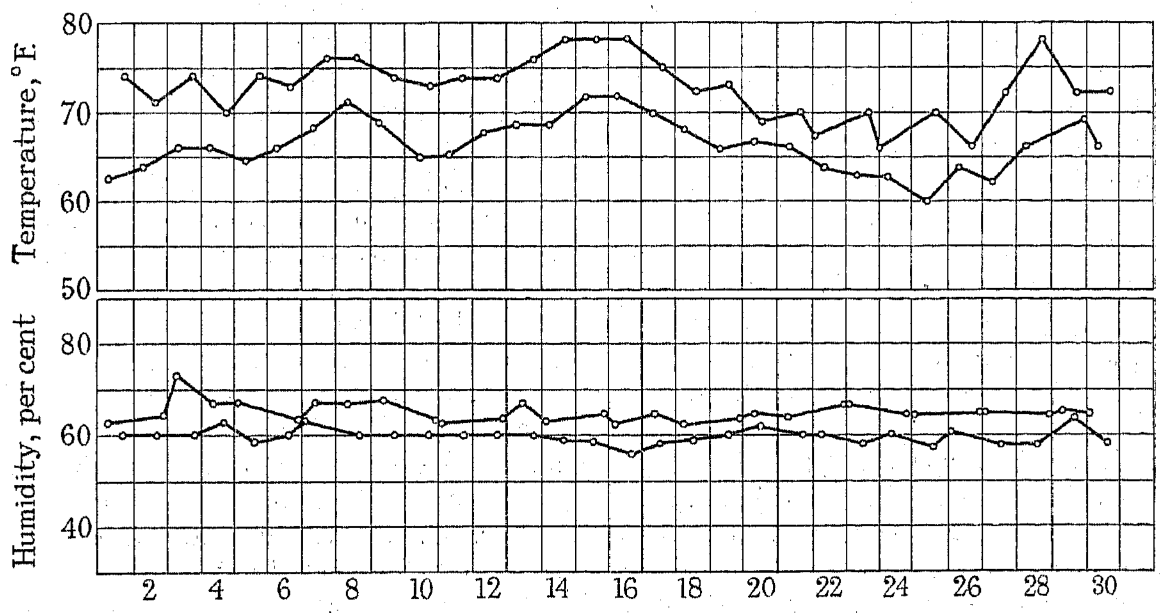


FIG. E.

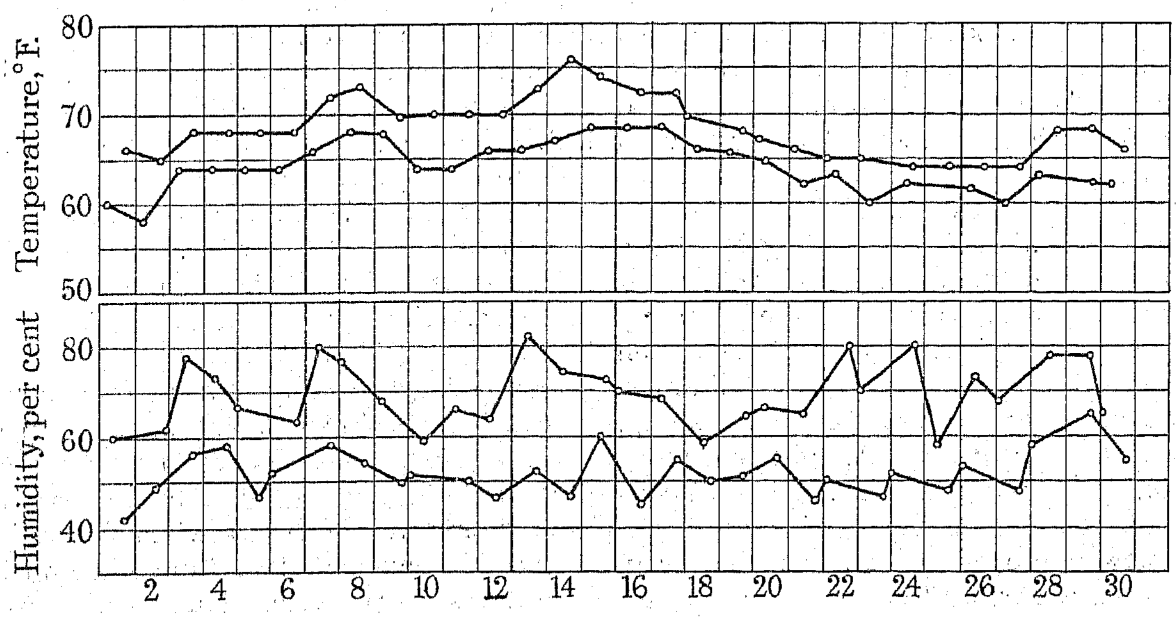


FIG. F.

Gallery should be kept within the limits of 55 per cent and 75 per cent. This has been effected very successfully, without the use of any refrigerating plant, by taking advantage of the stabilizing influence of hygroscopic material. The gallery contains a large amount of panelling and other woodwork, but this is painted, and its reaction to changes in relative humidity would be comparatively slow. The difference in moisture content of the air between the two limits of relative humidity is about 50 lb. The stabilizing medium—about 2 000 lb. of old unlined canvas fire hose—was put into ducts, through which a fan under automatic control from a hygrostat circulates the air as required. The same hygrostat controls the operation of water sprays in the air stream, at times when the relative humidity tends to fall too low. The storage capacity of the canvas within the prescribed limits is about 80 lb.

Figs. D, E, and F, show the results obtained during September 1934. Conditions in September offer the greatest difficulty to control by this type of plant. Fig. D indicates the maximum and minimum of the outside temperature and relative humidity for each day in the month, the time of occurrence on each day being approximately shown by the position of the dot. Fig. E shows the conditions within the gallery: it will be observed that the specified limits were not exceeded. Fig. F shows the conditions within an exhibition gallery at Hertford House, which is not provided with any special conditioning apparatus.

If a more systematic use could be made of this valuable property of textiles and other hygroscopic material, mechanical refrigeration would only be required to deal with comparatively rare peaks, and the amount of power necessary would be very greatly reduced. So far as is known, the installation at Hampton Court is the first of its kind, but the method appears to have a large field of application.

Mr. E. Kilburn Scott (*communicated*): It is unwise to " boost " electric heating too enthusiastically, because, as Dr. Faber has truly said, there are other efficient ways of heating large buildings, and engineers interested in steam heating are particularly alert. That there is another side to the question is shown by the fact that generating plant, the exhaust steam of which is utilized for heating of buildings and for process operations requiring cheap steam in bulk, is now being manufactured in large quantities. It is impossible to close one's eyes to the fact that there are technical and economical advantages in heating with steam, and this is indicated in the country that has done so much to expand the uses of electricity, namely the U.S.A.

In many cities of the U.S.A., bulk heating by steam is standard practice, and a still more significant fact is that electric power supply companies are very largely concerned with the steam heating. As has already been pointed out,* practically all the large public buildings, restaurants, hotels, and apartment houses of Pittsburg, are supplied with steam heat by the Allegheny County Steam Heating Co., which was started and is still controlled by the same concern as that which owns the principal electric power supply plants. In that city, as well as in Detroit, Kansas, and other centres, steam heat is given from boilers that originally formed part of electrical plant. For example, in Pittsburg, boilers that had been installed for electric supply purposes, but not used, were turned over to the supply of steam, and the generating side became a substation. So successful did the steam supply side of the business become that the company has now three of the largest boilers in the world each capable of giving 400 000 lb. of water per hour. It started to sell by-product steam; and now, two 5 000-kW turbo-generators utilize the drop in steam pressure down to that at which it is distributed, the current being supplied as an electrical by-product to the parent electrical concern.

* *Journal I.E.E.*, 1931, vol. 69, p. 1101.

A point to be considered is that electrical undertakings should take a leaf out of the book of the gas supply undertakings and sell heat as a by-product. It happens that the time is favourable, because a considerable number of the 500 electric supply stations which now operate are going to be disused, as the Central Electricity Board have in view only about 125 power stations for their purposes. This will mean the scrapping of a large amount of quite good boiler plant unless some other service can be found for it. Why not use it for giving public steam-heat supplies? It happens that most of the electrical power houses which will be superseded are near the centres of thickly populated areas, and are thus well situated for the supply of steam heat with short runs of piping to buildings.

In case the question is raised whether electrical undertakings have powers to supply steam heat, there is the case of the Stuart Street station, Manchester, which has given steam heat to surrounding buildings for some years. As a matter of fact, steam heating from electric power stations is no new idea, as can be confirmed by members of the Institution who visited Dresden about 33 years ago. It will be remembered that on that occasion some of the boilers at the electrical station were found to be supplying steam to the opera house, art gallery, palace, and other large buildings.

Mr. D. B. Williamson (*communicated*): There are several references in the paper to electrical control gear for heating circuits, and to the various troubles that are frequently associated with electromagnetic contactors. These are, in general, freezing of the contacts, slap action, and hum from the hold-in coil. In this latter connection it is recommended that the closing coil be operated through a rectifier.

In view of these difficulties it seems apposite to describe very briefly a new type of switch, which is a definite departure from the electromagnetic contactor. This is the glass sealed vacuum switch, which was recently referred to by Mr. Cheetham in his Chairman's Address.* Fig. G shows a pictorial view of such a switch. The movement is obtained by the expansion of the two grids of " heat wires " which are mechanically in series. The relay current expands these wires, and their increase in length transmitted through the movable contact arm produces sufficient movement on the main contacts in the contact chamber to make or break the main circuit. Such a switch has no arcing at its contacts, since it is evacuated, and of course no oxidization of the contacts is possible. Hum and slap are quite non-

* *Journal I.E.E.*, 1935, vol. 76, p. 57.

existent. The switch can be operated on a.c. or d.c. supplies up to 1 500 volts; it can be mounted in any position, and is unaffected by vibration. The switch produces practically no wireless interference, since no arc is drawn on the contacts. It has an inherent time-lag of about 2 sec., which is a distinct advantage in certain circumstances. Any thermostat or contact instrument can be used to control such a switch, and, since the control circuit is non-inductive, arcing on the thermostat contacts is practically eliminated.

It is appreciated that this switch cannot as yet handle the heavy currents with which the paper is mostly concerned, but, since vacuum switches have already been made up to 27 kW capacity, and since there is no inherent difficulty in producing still larger switches, it seems appropriate to draw attention to this new device, which may have an important bearing on switching problems of the future.

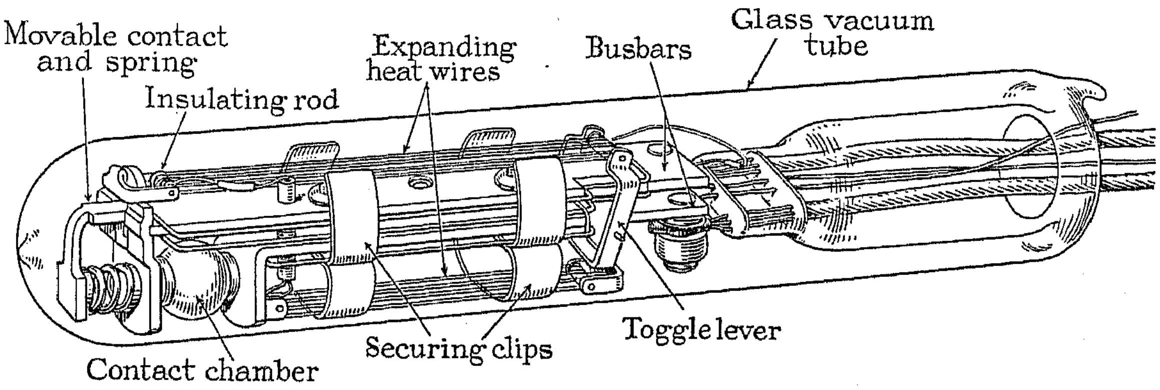


Fig. G.

[The authors' reply to this discussion will be found on page 539.]

North-Western Centre, at Manchester, 20th November, 1934.

Mr. A. B. Mallinson: I like the term "high-grade heat" used in Part I. We have been claiming that heating by electricity is in the end just as economical as heating by gas, coke, or any other medium; and we have in "high-grade heat" a term which is worth using and will be a good selling point. I recently, for instance, installed a small 60-kW electrode boiler in a private residence, the owner of which was quite prepared to pay a considerable extra sum to ensure getting absolute regularity of heating, i.e. high-grade heat.

On page 463 the authors put forward rather scathing criticism of our method of building with uninsulated roofs. It was a common practice before the War to seal up the loft space by plastering under the slates; or, on the coast, by cement-washing outside the roofs. The practice was dropped probably because of the shortage of plasterers and the high cost. Houses which are being erected by the million to-day all have the defect mentioned by the authors.

In Fig. 2 they give data for a building with a maximum demand varying between 180 and 1 000 kW. What is going to be the position of the user if, by reason of the low rates offered in the first place for off-peak supply, he has had installed one of the storage systems; and then the supply undertaking find their night load has reached a point when it is no longer "off-peak"? The user will have an installation having a peak of up to $5\frac{1}{2}$ times what he would have had with a unit system and thermostats.

Fig. 7 is a very interesting curve of the cost of grid supply to authorized undertakers. Such items as transformation and distribution losses, administration costs, capital charges, and profit, will have to be added if that curve is to be of any use to those who are trying to get people to adopt high-grade heating. What is needed is a curve of that character, showing the price at which electricity can be bought. Few supply undertakings are offering supplies at anything like competitive prices at present.

Part I, Section (8), mentions a contract for electricity at a lump sum per year; here, I agree with the authors, we are getting to rock bottom. The curse of electrical supply for the last 20 years has been tariffs. When we can supply electrical energy for all purposes at a fixed annual charge, we shall have started to make progress. At present, when a consumer signs an agreement for electricity supply he does not know until the end of 12 months what he is going to pay.

On page 480 there are references to dual thermostats. This is a small, but serious, point. I have already met with trouble in this connection; it is easily overcome as the authors propose. It has been standard practice for many years with steam boilers to have two safety valves, for the same reasons.

With regard to electrode boilers (Fig. 16), have the authors found that the insurance companies require the valves on flow and return pipes of boilers to be fitted with padlocks or other interlocks?

It is interesting to have the figures for the expansion of water (Table 10); I have often wanted these data for high temperatures.

Fig. 24 is valuable, but it would be interesting to know whether all the makers of heat insulating materials agree with the figures given in the curve.

In connection with scale-forming temperatures (Part IV), I have found that 140° F. can give a lot of trouble with certain waters. I think the scale question should have been dealt with to a greater extent in the paper. There is a decided field for makers of electric water heaters to embody a base exchange softener, to ensure

that soft, free-from-scale water, is used in the vessel. Another factor in connection with water heaters, where the water supply undertaking is softening by lime-soda before distribution, is the lime sediment settling in the water cylinder during the night. I have been amazed to find how much fine lime sediment has been deposited in the bottom after a few weeks' use.

In Table 19 the authors give figures for heat losses from pipes. Have they made any tests, by accurate electric measurement, to prove that the varying factors are really accurate? I have my doubts on this point, as the result of rough tests I have made. I cannot accept the differences claimed; neither can I agree with the difference noticed between the drawn-copper pipe when bare and when distempered or aluminium-painted.

In Part V, air-conditioning is only sketchily touched upon; in my opinion, it offers one of the biggest fields for development. Practically all our buildings are most primitive from the point of view of air control, but in the next few years, with the advance in the supply of cheap electricity, we are going to see a great advance in air-conditioning, in respect to filtration, heating, and cooling.

Mr. F. Buckingham: Electricity, to be competitive with other heating media, would have to be available at the very unlikely figure of 0·1d. per unit. The authors seem to have fixed upon 0·25d., and at that figure in certain areas, in London especially, there is something to be said for electric heating. There is, however, no readiness in this area to supply electricity, even for heating, at that price, and the reason is not far to seek.

An instance is given in the paper of a block of offices which has a maximum load of 1 430 kW. It will be appreciated that some 50 such blocks would be sufficient to fill up all the hollows in Barton's load curve. That in itself would make only a slight contribution to solving Manchester's smoke problem. In any case, the fuel in general use in large blocks of buildings is smokeless coke. When the load curve is filled up, the authorities will be confronted with the necessity of installing additional plant to deal with the heating load. Under such conditions, 0·5d. per unit is as cheap as electricity could be supplied, and at that figure it could not possibly compete with coke.

Anything which can be done by off-peak load electricity can be done equally well by smokeless solid fuel, without anyone knowing the difference. The facility which electricity offers for operating control apparatus largely makes this possible.

Mr. Mallinson spoke of "high-grade heat." High-grade energy should be used in a high-grade manner, and not in making low-temperature heat at 120° to 160° F. Electricity is the highest grade of energy available, and in its production there is much low-grade heat going to waste. For every kilowatt which Barton puts into the mains, energy at 4 times this rate is poured into the Manchester Ship Canal in just the form that heating engineers would like to have it available. The opportunity for making general use of this source of heat passed by when super power stations were decided upon. If the electrical industry had really laid itself out to supply heat as well as electricity, it would have enjoyed an additional source of revenue, and we should have been using the waste product of the electricity stations to eliminate smoke from our cities to a much greater extent than the direct use of electricity for heat can ever do.

The high-grade contribution which electricity can make to the heating problem was dealt with in a paper read before the Institution in 1930 by Mr. T. G. N. Haldane,* in which reference is made to the heat pump. He proposed to use the ordinary refrigerator on the principle of the Kelvin heat pump, by means of which it is possible to pump from the surrounding atmosphere or any other convenient source of free heat, many times the heat equivalent of the energy necessary to drive the pump, and to deliver it where it is wanted. Mr. Haldane dealt in particular with swimming pools, and proposed to adapt a refrigerator driven by an electric motor, using, as his source of heat, the heat in the outgoing waste water from the baths, putting the heat back again into the ingoing water. By this means, he would maintain the temperature of the swimming bath for about one-seventh the cost of the direct method. Judged by this standard, the Watford and Wembley plants cited in the present paper may properly be regarded as obsolete before they were started up.

Mr. W. E. Swale: It is of considerable interest to ordinary practitioners in electrical applications to be allowed an insight into the methods of specialists of the rank of the present authors.

The greater and more valuable part of the paper is devoted to practical details of design, construction, and operation; to those items which, as the authors say, are "calculated to bring credit to the industry that sponsors it." The art of building warming and water heating has indeed brought into being an amazing variety of appliances, which seem to follow, in the main, two ideals: (*a*) Attainment of comfort conditions, rather than merely temperature-rise. (*b*) Adaptation to exigencies of electricity supply.

The detailed study of the conductivity of water (page 475) is valuable. It is difficult to believe, for example, that in a radiator system supplied by a small electrode heater (Type A, Fig. 14) it takes nearly 7 hours to raise the current from 18 to 33 amps. As a result, owing to the slowness of the water circulation, instead of getting a straight-line temperature curve, as shown in Fig. 29, we actually get something like a sine wave, of amplitude about 14 to 18 deg. F. This difficulty might be overcome by the bypass circuit described on page 476, possibly in conjunction with a water-circulating pump.

The choice between the immersion heater and the electrode heater probably lies with the latter for ratings from 650 kW upwards. The beauty of the former is that it entirely gets over that contentious point regarding multiple earthing. There I would ask the authors for a little further comment. Have they heard of any complaints from Post Office authorities or from supply undertakings' mains engineers, regarding the stray currents which wander forth from the shells of electrode boilers? Time alone can tell whether these can be ignored. One authority, at least, has compromised by

* *Journal I.E.E.*, 1930, vol. 68, p. 666.

recommending the use of electrode boilers only on premises receiving e.h.t. supply, where energy is transformed on consumer's works, thus limiting the radius of influence of the possible stray currents.

Turning to Part I, Section (3), if everyone who has any influence in placing a contract, either for a public building or for a private house, were to capitalize his annual heating costs and relate them to the cost of insulating material the electrically heated building would, in my opinion, move far more rapidly into the practical picture.

The authors give some very interesting rules for the formulation of electricity tariffs; the Bedford load curves (Fig. 1), by the way, show that the sharp midday drop, common to large industrial loads, has been largely compensated, and that, on a presumably mild day in February, the system peak actually occurs at about 6.30 p.m. This is clearly due to the domestic-cooker load, and we arrive at the rather ominous condition where the fixed charges of the undertakings are determined by the consumer class which enjoys the lowest tariff.

The authors quote several "interesting contracts," as they call them. Some authorities tried these in Lancashire some 10 years ago, with rather unfortunate results. The authors also refer to the reluctance of supply authorities to quote unrestricted supplies for heating. It surely all turns around the question of diversity of demand. There is reason to believe that during a severe spell of frost there will not be a great deal of diversity, even with thermostatically-controlled electric heating loads. A fundamental difficulty, in my opinion, in the way of giving still lower heating tariffs is the high ratio of the total kWh needed for building warming to those required for all other purposes, i.e. light, power, cooking, etc.

The following three values illustrate this point: open-air school, ratio 14 : 1; large modern bank, ratio 7·4 : 1; Manchester Central Library, ratio 7 : 1. Surely, if it were considered economically sound to give unlimited low-voltage supplies at rates of 0·48d. for day units and 0·24d. for night units (these values represent the authors' ideal), the power and lighting load of the country's generating stations would be completely swamped by the heating load, and the electricity supply costs fundamentally upset. I admire the ingenuity of the arguments put forth, but am more than a little dubious about the wisdom of adopting these suggestions.

Would the authors consider it possible to get heating business on these lines: 0·8d. per kWh between the hours of 7 a.m. and 11 p.m., and 0·4d. between 11 p.m. and 7 a.m., on 5 days a week; and 0·4d. between Saturday midday and Monday morning? (Supply cut off on Monday to Friday, in the morning between 8.30 and 10, and in the afternoon between 3.30 and 5.)

There is, clearly, a very large amount of building-warming business to be obtained in this country; so much, in fact, that supply authorities are treading a little warily in the matter of tariffs. Such papers as this, in which much first-hand information is given in relation to existing installations, are of very material assistance in helping to clarify one's views of the precise nature of these important new applications.

Mr. F. R. Livock: With regard to the heat insulation of buildings, the authors indicate that to insulate a building will enable us to put forward a better proposition for electricity; but of course that is not so, because the fuel engineer can do just the same thing; his running costs will be reduced in exactly the same manner. In the case of fuel heating the difference between the running costs will be slightly less, but the percentage difference remains the same in each case.

On the question of immersion heaters, one manufacturer has ceased making fireclay immersers, for two reasons. It was discovered that there are two causes of failure inherent in this type. One is the unavoidable condensation of moisture on the elements, causing slow corrosion and consequent failure. The second cause is the creeping of the coils, bringing about short-circuiting of the turns and—eventually—breakdown. This has been got over in rather an ingenious manner by one firm. They commence with a cast-iron core which is something like a double H in shape. In the grooves or channels thus formed, the heating coils are placed. They are embedded in refractory cement and then the whole core is baked in an electric furnace, producing an entirely solid job. The core, after it has been baked, is die-cast in aluminium, and the finished product has the appearance of a 2-in. diameter aluminium rod. The advantage of that type of heater is that the element coils are rigidly fixed and condensation is impossible. In addition, owing to the large body of metal tending to keep down the temperature of the element wire, it is possible to increase the loading up to 25 watts per sq. in. and thus reduce the size of the immersers.

Referring to Fig. 31, I notice that the self-contained water heater and the displacement type of water heater are each supplied from a separate cistern. Both those types are actually connected direct to the cold-water mains, a cistern feed being unnecessary.

The authors mention the impulse switch; I think that this is one way of solving the old problem of peak load. It is quite possible and it has been done, to install an impulse generator at the electricity works, or the sub-station, and at peak periods send out impulses which operate the relays installed on the consumer's premises switching off the water heater or any other apparatus on an off-peak tariff. I think there is a great future for the impulse switch.

I anticipate that representatives of the supply undertakings will have a lot to say about conversion. The majority of heating intallations in this area are conversions, and not storage cylinders.

I also have experienced trouble with sediment. A 200-gallon water heater, when opened up after a period of 9 months, was found to contain several shovelfuls of sediment.

The question of swimming baths is rather a vexed one, and I should be glad if the authors would give us some further information on this subject. The electrical heating installation at Watford has been in operation for some time, and no doubt details of the running costs are available. There has been a considerable amount of controversy among swimming-bath engineers, and it is regrettable that more information with regard to baths heated by electricity is not forthcoming.

I should like to comment on Mr. Swale's suggestion as to a suitable tariff for electric heating. I do hope, from the manufacturer's point of view, that we shall receive in the near future tariffs which are a little more attractive than his proposal, which is less favourable than those already offered by a large number of supply undertakings.

Mr. S. Mc. I. Saunders: On page 464 the authors show a ratio of 4·34 to 1 for the amount of heat required to raise the temperature of a structure 1 deg. F. compared with the rate of heat loss at a temperature-difference of 30 deg. F. Strictly speaking, one cannot make a comparison like that because the first quantity is an amount and the second a rate. It could be equally correct to compare the amount of heat required to raise the temperature of the mass of the buildings through 30 deg. F. (the temperature-difference maintained inside) and the rate mentioned. The point is that one can make that comparative figure anything.

Mr. Livock asked for information as to the running costs of swimming baths. When I was at Watford some time ago, I ascertained that the average fall in temperature in 24 hours at the bath was about 1·5 deg. F. This fall may have been due to the fact the building itself was not warmed very much; because in another instance where the building (not electrically heated) was kept warm the fall in temperature of the water was only about 1 deg. F. a day. Generally speaking, little heating is required in the summer to maintain the normal temperature of swimming baths.

Mr. A. B. Stevenson: In the paper which he read 3 years ago Mr. Grierson* mentioned a device called the "Kata" thermometer, which was intended to measure not merely the room temperature but the actual comfort conditions of the building. I should be glad if the authors would outline the development which has taken place in that particular aspect of the subject since then.

(*Communicated*) The logical development of the comfort meter would appear to be a hollow body, say spherical in shape, which would contain water vapour or other volatile liquid, raised to and maintained at 98·2° F., the temperature of the human body, and which would radiate and convect heat into the surrounding air through an artificial layer of thermal resistance comparable to that of the human skin and underlying tissue. The heat supplied to this vapour, in electrical or thermal form, would be made to bear a definite ratio to the heat supplied to the particular section of the building concerned, by means of a shunt or bypass. Then this heat, required to maintain the temperature of the vapour at 98·2° F., would be a continuous measure of the additional heat necessary to maintain the comfort temperature, being referred to a zero condition of, say, 65° F., no radiant energy, and total darkness. Further, by the simple subdivision of the sphere into two separate halves and by the employment of water vapour at 98·2° F., the measurement of the amount of water vapour per hour passed through a special diaphragm into the surrounding air would provide a most reliable and convenient knowledge of the relative dryness of that air. By such means, suitably applied, not only the temperature and living conditions but also the humidity of the air can be kept under automatic and adjustable control. Other devices might be described for the control of ionization, ozone, and CO_2 content, but enough has been said to illustrate how the automatic control of comfort conditions can be assured.

* *Journal I.E.E.*, 1931, vol. 69, p. 1045.

Mr. W. Easton: In connection with the heat insulation of buildings, I think we are going to have great difficulty in persuading architects to adopt extensive heat insulation, because the modern tendency in architecture is towards providing the maximum amount of daylight in a building. With that object the general practice is to make windows as large as possible. One is now finding buildings that are little more than a steel framework filled in with glass panels. Structures of this kind will be very difficult to warm.

With regard to the soapstone radiator, I should like to know what the specific heat of soapstone is. Unless it is something near to that of water I do not see that soapstone has any great advantage over the cast-iron radiators mentioned by the authors. In my opinion these radiators have not received sufficient attention from heating engineers. They offer a solution of the problem of small-scale "off peak" heating; they can be installed in small offices and rooms, and allow the supply to be cut off during the afternoon peak period, leaving a sufficient amount of heat to tide the room over. I think the engineers who have been responsible for the design of these radiators have adhered too slavishly to the standard designs. Hot-water radiator apparatus is too heavy and expensive, and I think it would be better if made of light-gauge steel tubing having the largest possible water capacity for its weight, so that the amount of heat that could be stored in it would be the maximum. I have found that such radiators work very well indeed and are quite a reasonable proposition. The only drawback is their heavy cost in comparison with that of ordinary radiant heaters.

On the question of domestic hot-water supplies, the authors mention difficulties caused by expansion pipes running back to the cistern. The cost of installing feed and expansion pipes from cisterns placed in the roof to storage tanks in the basement is a serious deterrent to the installation of electric hot-water systems in the large old office blocks which are common in Manchester, and direct connection to the water main would appear to be the only solution to this problem. Is there any possibility of a valve being brought out which will permit of the heater being connected to the cold-water main? Such an arrangement would have to be something like a safety valve which will at the same time take the expansion of the water on heating.

The provision of hot-water supplies for restaurants and hotels is a very difficult problem, because the consumption varies so much in different establishments. If the hot-water supply fails just at the peak time, when lunches are being served, it causes tremendous confusion. Electrical engineers are at a disadvantage in providing such supplies, because once the tanks are run down there is no possibility of getting hot water for quite a long time, until the heater has somewhat recovered. Is it possible to introduce a type of tank incorporating the "circulator" tube, so as to provide quick recovery?

There is sometimes great difficulty in finding suitable

floor space for large water heaters. Those made in Great Britain are large in diameter, and it is not always an easy matter to find room for heaters which project 3 ft. from the wall. Manufacturers might do something towards providing heaters of smaller diameter and greater height, which could be more easily accommodated in odd corners.

Mr. W. Fennell: I was recently commissioned to ascertain what terms could be obtained for electricity supplies to cinemas in certain districts. In one town, electricity could be had for heating at the low figure of 0·38d. per unit, with only one condition, namely that thermostatic control should be adopted on the heater. Unfortunately this same undertaking persists in regarding the power taken to run the projectors as "lighting," because the screen is lighted. As suggested early in the paper, they may be charging too much for operation in order to give a spectacular price for heating.

The suggested all-round contracts will not do, in view of the grid tariff, which embodies a kW charge measured on the worst day in the year and, in conjunction with that, a very low unit charge. It seems to me that the only permanent and equitable basis on which to work is to pass it on the grid tariff to the consumer. The ideal scheme for a heating installation is a price 25 to 30 per cent above the grid tariff to cover overhead expenses, measured on the same basis as for grid charges. If consumers will keep off the peaks they have only to pay the unit charge of 0·3d., which is about as low as we can hope to go. During peak periods they can use a simple form of thermal-storage apparatus; or they could put in parallel with their electric heating installation a coal-fire boiler burning anthracite, and use that during those few days in the year when peak-load conditions exist. It is simply a matter of communication between the supply undertaking and the user as to what those days are.

Mr. Swale's suggestion of 0·8d. per unit from 7 o'clock in the morning until 11 at night (just the period when heat is required), irrespective of the actual peak-load conditions, and of 0·4d. from 11 in the evening until 7 in the morning, with two "rests," i.e. cut-off periods—1½ hours in the morning (when the consumer wants to raise the temperature) and from 3.30 p.m. to 5 p.m. (when the outside temperature begins to fall)—is not an attractive one. If the supply authority would consider offering the same 2-part tariff for electricity for heating large buildings as is offered for industrial power this would be equitable, and might secure the business. There does not appear to be any equitable reason why the 2-part industrial tariff should be confined to motive power.

With regard to the Kelvin heat pump, this ought to be developed seriously in this country. I wrote an article on this subject some 3 years ago for an American journal. A few months afterwards I received a highly appreciative letter from Wisconsin, in which the writer said he had a heat pump in use and was gratified with the result. I believe he utilized the refrigerator which he was using for cold storage in the summer, and adapted it for heating in the winter.

The specific heat of soapstone is roughly 0·2. The advantage is that it can be raised very much higher in temperature than water, and therefore by its use a good deal of heat can be stored in a small space. I have one in my office now, and it is satisfactory for use after dusk, when we cut off the heating circuit to save bulk-supply kW charges.

Air conditioning is an important subject. Electric heating is handicapped at present in connection with the plenum system, which is not as efficient as the ordinary system. There is a field for working in conjunction with hot-water systems, providing the power for water and air circulation in such cases where the actual heating work cannot be secured.

Mr. W. Kidd: The question of heating buildings is closely associated with tariffs, and from what has been said there seems to be some apprehension as to what may happen if we get a large water-heating load on the electricity supply system. I would suggest two lines of thought. First, that any hot-water storage system can be arranged to be an off-peak load. There is sufficient heat in the water in the pipes and radiators to maintain the room temperature for an hour, and supply authorities should reserve the right to decide that period. Second, if the water-heating load does level the load curve so that there are no peaks, then the cost of electricity for all purposes—heating, lighting, etc.—will be very much less than at present. In this case the kW charge, if the load factor is brought up from an average of 25 per cent to something like 100 per cent, will be about one-quarter of its present amount.

[The authors' reply to this discussion will be found on page 539.]

Western Centre, at Gloucester, 17th December, 1934.

Mr. H. C. Sanders: Referring to the scaling in electric water heaters, there is undoubtedly a tendency to heat water to a temperature which is unnecessarily high, thus increasing the heat losses and adding to the scale. Consideration of temperature, together with low loading per square inch of element wetted area, can do much to reduce scaling in electric water heaters.

It is a great help to find supply engineers placing the heating department in charge of an engineer who understands not only the apparatus but also the water to be heated. It is encouraging to find in many towns accurate information as to maximum temperatures and loadings permissible from the point of view of hardness for elements of various sizes.

Mr. J. B. J. Higham: Referring to the question of tariffs, in many cases unsuitable tariffs are responsible for the fact that consumers are not willing to go to the expense of electrical apparatus, when what they get out of it costs appreciably more than with existing methods. When, as in the district where I reside, a clause is introduced into the "all-in" or "domestic" tariff that energy can be had for 1d. per unit only if a 4-kW electric cooker is installed, those consumers who have purchased comparatively expensive gas-cookers are deterred from taking electrical energy for other purposes. In addition,

the standing charge is based on the number of living-rooms and bedrooms, whether wired for heating or not. As soon as these limitations, where they exist, are removed, the public will respond to the large amount of costly propaganda work which is now going on. I believe that in many districts this throttling of the free choice of the consumer has been done away with, and pressure should be brought to bear on authorities to remove these restrictions, wherever such are known to exist.

Sooner or later the domestic residence costing from £750 to £850 is going to be the real load-builder. At least 70 per cent of our suburban districts are made up of such buildings, and something ought to be done to cheapen the first cost of electrical apparatus for use in this type of house. I have estimated in my own case that the total cost of the hot-water system, including the dining-room boiler grate of modern design and burning coal, together with two modern gas-fires and a gas-cooker, cannot have been much more than £35 to £40. Until recently the average cost of electrical energy for heating and cooking was of the order of 2d. per unit, which is far too high. The charges are now, however, being reduced, and several restrictions removed. I should like to give the annual heating costs in my own case, averaged over a number of years, for a 6-roomed house (including kitchenette), and a family of 5: Coal (only one coal fire), £5; gas (2 fixed gas-fires, 1 portable gas-fire, poker, cooker), £6 10s.; electricity (lighting, and vacuum cleaner and electric iron run from lighting mains), £7; total, £18 10s. (say £20, as a round figure). For comparison, take £5 as the standing charge, leaving £15 for electrical energy at 1d. per unit; this will provide approximately 10 units per day, which is evidently on the small side for an all-electric house.

Mr. A. H. McQueen: The authors suggest that the principle of electrical heating is accepted. This is true up to a point, but there are many yet to convince, and to do this the closest co-ordination is called for between supply authorities, architects, and contractors.

The figures given in Fig. 2 do not appear to be comparable. It is shown that for a given output the loading required by an electrode boiler is greater than the loading for convection and electric ceiling-panel systems. One should bear in mind that the former is a night load, and therefore does not come on at peak periods. The latter may do so, and may also affect the maximum demand. In consequence of these possibilities, these schemes are not always economical, either from the point of view of the consumer or from that of the supply authority. Further, the direct switching-on of 460 kW with thermostats closed on a cold morning is not recommended. The use of convector tubes, ceiling panels, etc., is very limited, and there are distinct advantages to be gained with thermal-storage systems.

Dealing with the electrode boiler (page 476), the authors state that it is convenient to suspend the electrodes from the upper part of the vessel. Is it not a better arrangement, from the point of view of headroom and cable connections, to insert the electrodes through the base? From the remarks on page 479 one gathers that there is continual deposition of scale on the electrodes. In a "closed" system, after the deposition of the initial hardness, is it likely that deposition will continue? One would expect not.

The authors state that below 200 kW the immersion heater will usually be found to be a better commercial proposition. This figure appears to be high. Electrode boilers are working at much lower loadings and are found to be commercially possible. The electrode boiler is also more satisfactory from the point of view of protection, judging by the protective-gear difficulties (page 481) apparently associated with large-capacity immersion heaters. Moreover, electrodes are not so liable to failure as wire windings.

So far as the supply voltage is concerned, I would stress the fact that electrode heaters are usually an off-peak load, and therefore loads of 600 kW at 400 volts should present little difficulty to the supply authority. With the more extended use of this system, however, consideration will undoubtedly have to be given to higher-voltage distribution. The selection of suitable voltages to use for individual installations calls for collaboration on the part of manufacturer and supply authority.

The author quotes, on page 502, figures of from $1\frac{1}{2}$ to 3 deg. F. per day for the fall in temperature of an enclosed swimming bath. Figures of 0·5 to 1·5 deg. F. have, however, been obtained. The possible variation shows the necessity of suitable building lagging in baths as well as in other structures. The prevention of condensation on roofs should also be taken into consideration.

Mr. R. D. Reynolds: In connection with the heat insulation of buildings, can the authors say how cork slabs compare in regard to cost and heat-insulating properties with some of the fibrous materials, such as celotex, which are now so largely used? The authors do not appear to deal with high-temperature panels controlled by radiation thermostats, or with fan heater units for the re-circulation of air. In a paper of such scope this is rather surprising, as both systems have a very big field for the heating of buildings where the heat losses are necessarily abnormal, owing to high roofs, large glazed areas, thin walls, and excessive air infiltration.

I notice that tubular heaters are described as a convection system. Is this quite correct, in view of the fact that a radiation efficiency of 50 per cent is claimed for this type of heater?

Particulars are given on page 471 of a system of local hot-water heater units, equipped with immersion heaters. As more modern "convector heater" units are now available, I assume that the authors do not put forward this system as one representing present practice, where convection heating is required.

On page 495, 35 gallons is given as a likely hot-water requirement for a bath. I suggest that 16 gallons is a more likely figure, so far as the smaller type of modern house containing small baths is concerned.

Mr. J. F. Edgell: The authors employ the usual classification of water under two headings: (*a*) Scale-forming, or hard, water. (*b*) Soft, or corrosive, water. The normal average hardness of the Gloucester water supply is 28° Clarke, and it therefore comes under heading (*a*). (Mr. Edgell here exhibited an element of a domestic water heater.) It will be noticed that on the specimen shown considerable corrosion has taken

place not only where the scale has cracked off the heater tube, pulling the protective metal and fragments of copper with it, but also on top of the anti-drip device, where mechanical damage of the above nature does not take place. It would appear from this that Gloucester water is also corrosive and may be classed under heading (*b*) in addition to (*a*). The scale is deposited in the form of a blanket over practically the whole of the tubes, forming them into one conglomerate mass; this is typical of the water under discussion. Further, the scale does not tend to spread the tubes. In Bath, where equal hardness is experienced, the scale formation is of completely different form and nature. The scale forms as a small mass in the crutch of the tubes, extending upwards for 2 or 3 in. only, the upper portion of the tubes in most cases being completely free from scale. The deposit appears to expand after solidifying, causing the tubes to spread; in extreme cases the tubes crack off at the baseplate. The water apparently does not corrode the interior of the heater. These facts suggest that the degree of hardness alone is not a guide to either the amount of trouble to be expected or its nature. The apparatus plate shown is that of a 1½-gallon cistern which has been on test for just over 12 months. During that time 1 160 kWh have been consumed; measurements of the water supplied have not been taken. It can be assumed that after 8 months' operation on Gloucester water a scale deposit having a maximum thickness of ½ in. will cover the tubes. If the dissipation per sq. in. of heater tube is high, as in the present case, the scale sheds, but only in thick layers, and invariably pulls away metal. In two cases of test heaters, the heater tube has been punctured in less than 18 months owing to this effect.

The heater at present in general use is satisfactory purely on account of the low dissipation per sq. in. of the heater tube exposed to the water. In the 12-gallon size this is about 5·5 watts per sq. in. Where greater separation of the heater tubes is possible, and consequently the area exposed to the water is not reduced by scale bonding the tubes together, a greater dissipation is permissible. Success is obtainable only by keeping the watts per sq. in. low, and the tubes widely separated.

On page 495 the authors refer to water temperature in connection with scale deposit. My experience has been that even at 120° F. practically the same troubles exist. This low temperature is, however, impossible in most cases, as it increases the capacity of the cistern necessary to such an extent that its accommodation becomes a problem. The average modern bathroom requires certainly not less, and will often accommodate not more, than a 12-gallon cistern working at 160° F.

In Table 16 the authors show an "English house" as requiring 15 to 20 gallons of hot water per head per day. I have been unable to produce such figures. The average in Gloucester would appear to be about 4 gallons (at 160° F.) per head per day. This figure is the average of those of 7 consumers who obtain all their hot water electrically.

Mr. B. C. Robinson: With reference to Mr. Edgell's exhibit of the effect of Gloucester water on the element of a domestic water heater, I can confirm that a layer formation may force two parallel blades apart. An element removed recently in the Stroud district after some 3 years' service had suffered in this way.

In my district, electrical contractors install storage heaters with fixed thermostats set at about 190° F., without making allowance for the hardness of the local water. Trouble follows, and the householder appeals to the supply undertaking. We ourselves favour a setting of 150° to 160° F., but some contractors are slow to learn such details. Perhaps the manufacturers can tell us the additional cost of adjustable as compared with fixed thermostats. The West Gloucestershire Power Co.'s area is notorious for its hard water supplies, and we should like to have a say in the matter whenever a water heater is being installed.

Mr. W. A. H. Parker: In Fig. 2, which shows a comparison of the various systems of room heating in terms of connected load and maximum demand, it will be noted that in the case of thermal-storage systems the supply is only available for 12 hours each day. The point which we supply engineers have to consider is whether we can deal with this high demand during off-peak hours. If we can, the cost of supply may then be lower than that of the alternative systems, in spite of the increased demand. The authors speak of supplies being afforded at 500 units per £ for an unrestricted supply, and 1 000 units per £ for a restricted supply; I consider that both these figures are capable of attainment for large supplies, especially if we can afford the supplies at high voltages, thus cutting down the losses in transforming plant, etc., to a minimum. A system of heating by thermal storage on a yearly-contract basis, with relay switching controlled from a central point so as to ensure off-peak supplies, appears to me to offer the correct solution of the problem.

In conclusion, I should like to ask the authors whether they have any figures for the annual consumption of intermittent as compared with continuous heating of offices and similar buildings. In other words, does it pay to shut off the supply during the periods for which the rooms are unoccupied?

Mr. F. H. Corson: I doubt whether there is good ground for the suggestion on page 462 that the absence of combustion methods of heating gives the architect greater freedom in siting buildings with respect to the prevailing-wind direction. Some duct or flue must be provided for the extraction of vitiated or dry air from the top of the electrically-warmed room, and the lower temperature in such a flue compared with that in a combustion-heated chimney might necessitate even greater regard to the prevailing wind than is necessary with older methods. Mechanical methods of air extraction may be necessary in any case, and emphatically so if the direction of the prevailing winds is to be ignored. The common practice of blocking the existing chimney to prevent loss of heat, without the provision of alternative means of ventilation, produces conditions little if any more satisfactory than the cold draughts across the floor which are characteristic of even the best combustion methods of heating.

I think that the authors' reference to the lower cost of the small coal used in generation may be criticized. Under present conditions small coal is a by-product of the process of getting large coal, and its low price depends

on the continuance of this process. As electric heating gradually restricts the use of large coal, the price of small coal will be likely to advance. This tendency is already in evidence.

I am very glad to have the information given in the paper upon the question of heat insulation of buildings, and I think that this is perhaps the key to effective competition by a high-grade and relatively expensive form of heat. I prefer the policy of developing the very great advantages possessed by electrical methods, to that of selling a high-grade commodity at a price approximately equal to that of an inferior one. The heating load alone may in time exceed, for a few critical weeks in the year, all other types of load connected to the average supply system; and although it may be reasonable, in the early stages of development, to regard heating largely as an off-peak load, I feel some uncertainty as to the ultimate possibility of doing so. The sale of heating units must, in this country, be small in relation to a kW demand necessarily made during a period when most other demands are at their maximum, and I feel a good deal of doubt as to the permanence of the suggested tariffs, embodying figures of the order of 500 to 1 000 units to the £, for such a class of supply. Apart from this, however, it seems prudent, by the more efficient use of heat, to try to neutralize the initial handicap of generation, where 10 000 B.Th.U. from coal are required to produce 3 400 B.Th.U. in the unit of electricity.

I should like to raise the question whether lump-sum payment for unmeasured service, contemplated in an all-in yearly charge, is not likely to produce very grave difficulty from the point of view of the "undue preference" clauses of the Supply Acts.

Mr. B. L. Price: Referring to the pollution of the atmosphere and to coal conservation, it has been demonstrated elsewhere that the common domestic grate is more efficient than the electricity supply. Which, therefore, conserves fuel the more, or pollutes the atmosphere the less? Disconcerting as this knowledge may be, I believe the problem will evolve its own solution. Let us develop the heating load at bare cost until it becomes such a preponderant proportion of the total that perforce it will have to carry its own overhead charges. Nature has erected a barrier to such a principle of heating; but surely on the other hand she has ordained that we exploit the reversible heat-pump method which was the subject of a paper by Mr. T. G. N. Haldane.* This method would do for heating what the metallic-filament lamp did for lighting. Mr. Haldane's paper is a notable omission from the authors' Bibliography.†

Passing to the technical aspects of general interest, I should like to examine from first principles the question of the most suitable way of applying heat. The sensations of heat and cold depend subjectively upon the nervous system, but apart from this there are external controllable conditions. Air in circulation is required for respiration and perspiration. For the former it must be neither too hot nor too dry, while for the latter it must not be too humid. Comfort depends upon the temperature of the deeper tissues and not on that of the surface. Radiant heat on the panel system should therefore be more effective than warm air on the plenum system. The former penetrates to the tissues and evaporates the exuded moisture, leaving the air comparatively cool and pleasant. Incidentally, there is a saving of the heat which would be discharged with vitiated warmed air.

Now, regarding the question of continuous or intermittent heat, the problem is analogous to the charging of a condenser or to the design of a regulator resistance. Let H = heat flow, C = heat capacity of building, ϵ = emissivity, and θ = temperature difference. Then

$$H = C\frac{d\theta}{dt} + \epsilon\theta$$

When ϵ is zero, all the heat is returned into service. When C is a minimum the heating period will be in phase with the occupational period. According as C is increased, so will the heating period advance upon the occupational period. The ideal condition would be $\epsilon = 0$ and C large enough to return the periodic heat within desired limits of temperature. If ϵ is large it will certainly not pay to heat continuously an intermittently-occupied building. A large value of ϵ also favours a convection system.

In conclusion, I should like to have the authors' observations upon the method of superimposed harmonics for selected load control, if applied to a system of about 30 000 kW capacity.

Mr. J. C. Wigham: In the case of the large-scale heating schemes shown in the authors' slides, are the consumers satisfied with the apparatus, and are both the consumers and the suppliers satisfied with the price? One of the big water-power supply concerns in Canada which I visited a few years ago was supplying 1 million units a day for steam-raising purposes in a paper mill, at the phenomenally low price of 0·1d. per unit or thereabouts. One wondered whether it paid the suppliers, but when a supply is worth £150 000 per annum it quite alters the possibilities. Another interesting example is the supply for steam-raising purposes to the laundries attached to the immense blocks of workmen's dwellings recently erected in Vienna.

[The authors' reply to this discussion will be found on page 539.]

North Midland Centre, at Leeds, 8th January, 1935.

Mr. C. T. Melling: The authors dismiss the fundamental issues of their subject with the words (page 462): "it has been assumed that the principles of electric heating have been accepted"; a brief statement of the conditions to be achieved in the heating of a building would have been desirable.

On page 467 it is stated that the mean indoor temperature usually required in residential and office buildings is 63° F. It is generally admitted that a temperature of 63°–65° F., for air, walls, and contents, of a room, gives a condition of heat comfort; but that with increased radiation to the occupant a lower air temperature suffices. For example, an air temperature

* *Journal I.E.E.*, 1930, vol. 68, p. 666.

† This has since been added.

of 55° F. is appropriate when the mean horizontal component of radiation is 75 B.Th.U. per sq. ft. per hour.* Indeed, one of the authors has stated† that he finds his office comfortable at an air temperature of 55° F. with a 2-kW radiator in use. The reversion to 63° F. suggests either a change of opinion, or, more probably, that in his experience public prejudice demands high air temperature in favour of an alternative condition of heat comfort. This is unfortunate, as the higher air temperature involves a larger amount of heat, and electric heating is placed at a disadvantage when the competition is one of selling heat units. The call for cheaper electricity as a means of obtaining the heating load could with advantage be one for further research into the fundamental problem.

Heat comfort in buildings depends not only on air temperature and radiation, but on humidity and air movement. Air-conditioning depends too on temperature, humidity, and air movement. Only a brief closing section of the paper is devoted to air-conditioning, whereas, for health, it is of as great importance as the heating problem. Apart from Table 24, conditions of good ventilation are not formulated by the authors. Table 25 suggests that a low concentration of CO_2 is a criterion of good ventilation, whereas with equal concentrations of CO_2 the ventilation may be either very good or very bad, depending on smoke, fumes from the processes carried out in the building, and the evaporation from the skin and lungs of the inhabitants. This last factor is determined largely by air temperature and humidity. In general, the ventilation of buildings is insufficient, owing no doubt to the extra heat loss involved in changing air at 63° F. For example, a building of 300 000 cub. ft. capacity may have a heat loss at 63° F. of 750 000 B.Th.U. per hour, of which 550 000 B.Th.U. per hour may be due to 3 air-changes per hour (outside air temperature 32° F.). Increasing the air-changes to 6 increases the heat loss to 1 300 000 B.Th.U. per hour. On the other hand, with an air temperature of 55° F. with heat comfort maintained by radiation, the required heat input would be approximately 600 000 B.Th.U. per hour, while the improved ventilation (6 air-changes per hour) would increase the heat loss to approximately 1 000 000 B.Th.U. per hour. Improved ventilation can be achieved economically with an air temperature of 55° F., provided that the air ingress and internal air movement are well designed. Moreover, the lower temperature-rise of the incoming air results in a higher percentage humidity and avoids heat loss in the evaporation of water, which would be required to maintain the humidity at a reasonable percentage were the air temperature 63° F. or higher.

If then the attack on the general problem were to determine the conditions of health and heat comfort which could be obtained for the least amount of heat, applied through the adaptability of electrical methods, the use of electricity as a heating agent would be helped more than by competing on the older lines, through the sale of upwards of 1 000 units per £. If the latter method succeeds in capturing a large proportion of the heating load, it may cause embarrassing changes in local distribution peaks.

Mr. F. L. Fletcher: The authors' criticism of the blade type of immersion heater is rather severe. Referring to the blade type of heater fixed horizontally on the side of a vessel, they state first that it is essential for the blades to be fixed on a vertical axis; secondly, that the blades are not withdrawable from the sheaths; and thirdly, that the use of tubular-type immersion heaters has rapidly become recognized as standard practice. From personal experience I find that the position of the blades, i.e. whether on a horizontal or a vertical axis, makes very little difference. Secondly, the blades are, in the majority of cases, withdrawable from the sheaths. To illustrate these two points I would refer to an installation where 20 3-blade immersion heaters, mounted on a $2\frac{1}{2}$-in. screwed boss, were arranged to form a 120-kW bank. The heater was put into commission in 1929, and although only 5 out of the 60 blades were mounted on a vertical axis and at least 12 were practically horizontal, none of the blades has failed. With regard to withdrawability, 26 of the blades were recently withdrawn and replaced, owing to damaged terminals, caused chiefly by the use of copper for the connections. The copper had oxidized, causing arcing and loose connections.

From evidence obtained from the electrical Press and from other sources it appears that the proportion of blade-type heaters, rather than decreasing, is rapidly increasing. Owing to the low temperature-gradient between the resistor and the fluid in the blade-type heater, and to the fact that each individual blade occupies less space, the size of immersion heaters is considerably less than that of tubular heaters. As an example of this, using a blade-type heater, a loading of 108 kW can be fitted through a 14-in. diameter hole with an immersed length of only 3 ft. $2\frac{1}{2}$ in., the loading being well within the region of safety, whereas according to the paper a tubular heater with the maximum watts density would require a hole of 15 in. diameter and would have an immersed length of about 4 ft. 6 in. for a loading of only 90 kW.

In view of these remarks perhaps the authors will give us their reasons for subjecting the blade type of heater to such severe criticism.

Mr. D. H. S. Sanderson: My criticism of the refractory type of former illustrated in Fig. 11 is that the resistor is operating in air, and in consequence will oxidize at a rate dependent upon the temperature. If the temperature is kept down, the rate of oxidization is slow, but it does take place; oxidization increases the resistance of the resistor and thus reduces the kW rating of the heaters, and, in time, causes failure. Further, with a more or less open-wound type of heater fixed in a vertical position, i.e. from the top or bottom of a storage vessel or heater, there is a tendency for the coiled resistor either to sag or to creep upwards.

The authors also mention the twisting together of a few turns of the resistor in order to reduce the temperature at the terminal end and so prevent damage to cables. I think the best method of overcoming this is for a solid metal rod or link to be used of considerably greater section than the resistor, thus increasing the section 20 or 30 times.

* M. Fishenden: "The Heating of Rooms," Fuel Research Board, Technical Paper No. 12 (H.M. Stationery Office).
† *Journal I.E.E.*, 1931, vol. 69, p. 1055.

Turning to page 497, where the alternatives of local or central heating are discussed, I think that the choice is dependent to a large extent on the type of house. In large houses with a number of bathrooms and with bedrooms each fitted with hot water, and where the length of pipe run is very great, local storage-heaters should be used; but in houses costing up to £1 500 where the pipe runs are relatively small, and where, particularly in the North, most of the houses are already equipped with coal-fired back-of-fire boilers, the conversion system of fitting a heater or heaters into the existing storage tanks or cylinders is far cheaper. I am rather surprised to find that in the South quite a lot of houses costing £1 500 are not equipped with a hot-water system heated by a back-of-fire boiler. I was once told by an engineer well known in the South that there were at least 50 per cent of the houses in his town not so equipped. In such cases I think that the only system which can be employed is that of local storage heaters at the points of supply.

Mr. R. M. Longman: I would draw attention to electric heating as a source of load, particularly night load, for helping to fill the valleys in our daily load curves. Loads of this nature are a most desirable acquisition; they will lead to increased efficiency in operation and make it possible to adopt larger generating units, which are at present handicapped by having to shut down owing to the lack of load. From this it follows that such loads can profitably be taken on at a very low figure, and the big diversity therein must also be borne in mind.

Referring to room heating, the desideratum is to keep the feet warm and the head cool; why not therefore apply heat at floor level—through the floor rather than from the ceiling?

From a hygienic and cleanliness point of view, electric heating in domestic premises must be urged at all costs. There is no doubt that air pollution and a soot-laden atmosphere come chiefly from the domestic grate, a fact to which anyone living in a previously clean area, and where recently a large number of houses have been erected, can testify.

Domestic water heating by electricity must be advocated along with electric cooking and electric radiators, thereby enabling coal fires to be eliminated for 6 months of the year. I have been well satisfied for 10 years with the blade type of heater in a domestic hot-water cylinder.

I have been surprised to see so many large installations, i.e. exceeding 400 kW, operating at 400 volts. It would appear that, for anything above 300–400 kW, 6 kV or 11 kV would be preferable. Possibly in the cases in question there is a transformer on site to give the whole supply—heating, cooking, lighting, and radiators.

A point to be remembered in regard to contactor-gear control of such equipments is that the contactors will probably have to operate at full load for many hours on end, and must be liberally designed and rated for this work.

Mr. H. Pickard: Referring to Fig. 29, it would be interesting to know whether the valve controlling the hot-water supply had a bypass. The valve apparently opened at about 8 p.m. and remained open practically the whole of the night, presumably in order to get the temperature back to the thermostat setting. A bypass in the valve would have obviated that considerable period during which the valve was open.

Have the authors any experience with equipment for forecasting degrees of atmospheric temperature-change? If we are going to have a frost, then the thing to do is to pump increased heat into the building. I have had some experience of an apparatus which would predict a drop in the outside temperature of 8 or 10 deg. F. Is the adoption of such equipment likely to become general? It consists primarily of a resistance thermometer fixed upon a blade projecting into the outside air, about 100 ft. high. The temperature at that height seems to fall in advance of the temperature lower down.

The authors refer to thermostats as being very reliable; my experience has been rather the reverse. I have used the mercury type and the open contact type, and have had a fair amount of trouble. If the thermostat goes wrong, the whole of the control, particularly that of the electrode boiler system, is thrown out of gear.

With regard to losses through tiles in roofs of buildings, the results of a few thermal tests which I have made agree reasonably well with the figures given in Table 1. I also carried out tests on a slated roof, and was amazed to find that the losses were roughly two-thirds of those of the tiled roof. If the authors have any figures for tiled roofs I should be very glad to have them.

Mr. W. Dundas: I am inclined to doubt whether electric heating on a large scale is able to compete successfully with other methods of heating, but I have been impressed by the extent of recent developments indicated by the many illustrations of large electrical heating installations shown on the screen.

Unfortunately, the heating of buildings is a seasonal load coinciding with the maximum demand of the station, and it is difficult to see how its influence on the station peak can be avoided, which is a concomitant condition of low-priced units. I do not agree with the authors' remarks as to the low efficiencies of coke-fired boilers; in the majority of cases it is not possible for electric heating to compete on a heat basis with modern coke-fired boilers. It would be helpful to know something of the savings in other directions, and of the added advantages obtained with electrical heating which turn the scale in its favour.

Referring to the heating requirements for public baths, I recently had occasion to investigate the possibilities of electric heating, and found no difficulty in dealing with the plunge bath; but the requirements for other services—slipper, Russian, and other baths, laundry, drying chamber, etc.—completely upset the scheme. It would have been necessary to supply electrical energy at a little over 0·1d. a unit to compete with a coke-fired boiler installation.

Mr. S. R. Siviour: I should like to refer to the authors' statement (page 479) that there is some question whether they can get energy for large heating supplies from the ordinary networks. In my opinion we could not tackle these heavy loads on the average network. In fact, we should not think of dealing with them at low voltage—it would generally be uneconomic, especially as we nearly always get such loads at the far extremity

of our system. In most cases, loads of this magnitude would be economically dealt with at high voltage.

There is a reference on page 480 to the control of the load; I think the authors might be a little more optimistic in regard to the adoption of some of the systems to which they refer. The ripple system for street lighting has been successfully tried out in this country, and on those systems where 5-core cable is used for control of street lighting the fifth core may become redundant and be transferred to the control of this heating load.

There is a good field for the development of control-systems to deal with this heating load under the incidence of an attractive off-peak tariff.

Miss L. M. Sutton: Referring to the authors' remarks on solid-fuel fires (page 462), what is the objection to smokeless fuel? At present a solid-fuel fire provides the best method of disposing of household refuse, and this problem will have to be seriously considered before electrical heating becomes general.

[The authors' reply to this discussion will be found on page 539.]

SOUTH-MIDLAND CENTRE, AT BIRMINGHAM, 14TH JANUARY, 1935.

Dr. C. C. Garrard: When one is selling lighting one is selling not current but photons, and when one is selling heating one is selling calories; a photon is worth intrinsically more than a calorie. Even if the load curve is uniform, lighting should be charged at a higher rate than current for heating.

One of the difficulties in connection with electrode boilers is the natural variation in the conductivity of the water, which is tremendous. Before one can design an electrode boiler it is necessary to get a sample of the water to be used in it. As regards the porcelains, a great point is that bubbling should not occur at the surface of an electrode, and therefore the cross-section of the water surrounding each electrode should be larger than that in the space intermediate between them.

An interesting point, which perhaps is worth consideration, was brought to my attention by a friend. He had found a relation between the number of cable faults per yard, or per mile, and the distance of the fault from the neutral-point earthing resistance. His theory was that the neutral-point earthing resistance prevented faults occurring on the cables in its immediate neighbourhood, and from that he deduced the very great advantage of electrode boilers; he said that if he could have a large number of electrode boilers on his system he was convinced that cable faults would practically disappear.

I do not think the question of duplication of plant can be settled in principle; it depends wholly on the type of installation. For example, in a cinema heating system it is obviously not necessary to have any duplication, because during the summer the plant can be overhauled; but in the case of a laundry the conditions are different, because it is in use all the year round. There is one point I should like to raise as regards electrode boilers for laundries; I refer to the regulation when the load fluctuates violently. If one regulates the boiler by varying the height of water in it, when the load goes off one is faced with the difficulty that water has to be suddenly expelled from the boiler, and a certain amount of hot water is lost. I should like to know whether the authors can recommend any solution of this difficulty.

Mr. E. A. Reynolds: One of the main impressions I have received from the paper is that the electrical engineer will have to be thoroughly conversant with hot-water heating in order to deal with modern problems. We must not forget that the small low-temperature heating installations will play a very important part and provide a most useful load to the supply undertakings in the future, when a suitably low economic rate can be provided for this service. There is a large field for development in domestic and office heating, for which quite a low rate might be charged when it is automatically controlled.

Table 1 shows the extreme importance of heat insulation, a matter that should be very strongly brought to the notice of architects, as when the electrical engineer is called in the building is usually partly finished. Very few architects realize the yearly loss in cash which is due to poor heat insulation. From the figures given in the paper it appears that with energy at 0·5d. per unit the heat loss through an ordinary flat concrete roof costs about 16s. per annum per 100 sq. ft.; if a cork lining is inserted under the concrete this figure is reduced to 7s.

Turning to page 464, I notice that according to Dr. Faber the heat loss in buildings is 0·45 kW per cub. ft. The temperature-difference is not given, but I presume that this is 30 deg. F. as in other parts of the paper.

At the top of page 466 the heat losses in a building are given as 300 kW, and the maximum load at which the heaters will work is assumed to be 60 per cent of this; the latter figure does not appear to be quite correct.

The arrangement shown in Fig. 8 seems hardly fair to the tenant who, apparently, has to pay for the landlord's heating and his own excess load; some arrangement should be made whereby a tenant only pays for the excess.

The suggestion that immersion heaters should be fitted into calorifiers supplied by coke-fired boilers opens up quite a possibility of a useful summer load.

Dealing with domestic water heating, Prof. Parker Smith gives the hot-water consumption as $10\frac{1}{2}$ gallons per person per day, whereas in the present paper a figure of 20 gallons is taken. Although the authors' calculations based on that figure show quite a satisfactory result, I think that the figure of 10 gallons per day is a more usual one for domestic work.

Tables 17 and 18 give the heat losses per day for cylindrical water storage heaters: the two tables are for different sizes of water heaters, and are given on different scales, but on reducing them to the same scale Table 18 gives a much lower heat loss than Table 17. It would be interesting to know which is to be accepted for usual practice.

Mr. F. S. Naylor: The authors state that 1 000 units per £ is an economic rate for this type of installation.

There are a number of supply undertakings in the country which will not drop below a figure of 0·3d. per unit, and I should like to suggest that it is almost impossible to obtain this class of business with such a high rate as 0·3d. I only know of one case where it was possible to justify on an economical basis such an installation, and that was in a case where a high minimum guarantee had to be paid by a hospital in a rural area. In this particular instance the high minimum payment had to be made in view of the fact that it cost a considerable sum to take a line from the nearest point of supply to the buildings.

On page 496 the authors suggest various figures to be taken in computing the hot-water requirements for buildings, and in general they suggest 25 gallons per person per day. They also point out that it is sometimes very difficult to compute the exact quantity. This is perfectly true, for in a case I examined—an agricultural college—the consumption amounted to as much as 45 gallons per person per day. This high rate was due partly to the considerable number of baths taken by the students, and partly to the heavy consumption in the model farm attached to the college.

With regard to the authors' comments on the reluctance of many supply authorities to permit consumers to obtain heating on a 2-part tariff during the day and a special cheap rate during the night, the reason for this is that most supply undertakings are very conservative just now with regard to the heating load because they are afraid of the effect it may have on the maximum demand in December, and generally speaking they look upon a heating load as a balancing load only —something to fill up the night period—and not to be employed during the daytime. On page 465 the authors give some curves relating to the Bedford area of supply; I should be very grateful if they could be a little more explicit in connection with these curves. Probably an analysis of them would be an advantage. It would be possible to superimpose curves obtained during the summer, i.e. during the heating off-season, to show how the heating load has affected, if at all, the maximum demand during peak periods in the winter.

Considering the point generally, I do not anticipate that any progress will be made with direct electrical heating during the daytime, until research work on a statistical basis has been carried out to show quantitatively the effective maximum demand of heating loads per kW of connections. A figure of 0·5 kW of effective maximum demand per kW of connected continuous thermostatically-controlled heating loads is sometimes employed, but I believe this is far too high.

Research work is badly needed in the manner suggested, in order to establish the proper basis for the formulation of tariffs for continuous thermostatically-controlled heating, which I believe will ultimately prove to be the most valuable of all loads.

Mr. R. Dean: Most people to-day are agreed that electricity as a heating medium is the nearest approach to the ideal. The main deterrent, however, to its general adoption is undoubtedly the question of running cost. In the case of the larger installations a thermal-storage system is invariably installed, and for this type of heating the figure must be certainly not more than 0·25d. per unit and, if possible as low as 0·2d. This figure does not include any fixed cost per kW.

The ideal load is one of 100 per cent load factor, but it is easy to overlook this fact and to offer tariffs for summer and night loads which are even lower than for loads of 100 per cent load factor. This, to my mind, is basically wrong, and is equivalent to arguing that the part is greater than the whole. The problem which most often confronts both supply undertakings and users is the small type of heating installation in which either tubular heaters or radiators are intended to be used. If we take 1 000 units per annum as the average consumption per kW of heating installed, and £8 per kW as a fairly low average figure for the supply authorities' fixed charges at the l.t. consumer's terminals, fixed charges alone represent approximately 2d. per kWh. Even allowing a 2 to 1 diversity factor, the fixed charge would still represent 1d. per kWh. In many undertakings there is very little margin between the early-morning peak and the peak load of the day, and almost invariably radiators or tubular heaters are required in the early morning, say between 7 and 9 a.m. If lower tariffs were offered for this class of heating, the margin between the evening and morning peak would become less. There is again the definitely abnormal peak load in which such appliances can involve the supply authority during a prolonged spell of particularly cold weather. Such weather does occasionally continue for a few weeks, and at such times radiators are put into emergency use as a safeguard against freezing water-pipes, car radiators, etc. Such a load can conceivably have a load factor as low as 2 to 3 per cent, and may incur a supply undertaking in heavy charges on account of maximum demand. This, on grid tariffs of £3 to £3 10s. per kW of demand, is rather a serious item, and a deterrent to the introduction of lower tariffs for spasmodic heating. A further point to bear in mind is that radiators and tubular heaters are normally only a winter or half-yearly load. For these reasons I feel that anything less than ¾d. to 1d. per unit cannot be justified for radiators and tubular heaters which are not thermostatically controlled.

Mr. C. Kibblewhite: To enable a supply of electricity to be put forward on an attractive basis as a means of providing heat and hot water to large buildings, it seems that a figure in the neighbourhood of 0·2d. per unit must be quoted. This leaves little, if any, margin for the distributing authority after the Central Electricity Board's charge per unit has been met. Can the authors say whether there is any likelihood of the Board being able to quote a special rate per unit to the distributor for off-peak supplies of the type referred to in the paper?

Finally, I should like to know whether the earthing of the supply system by the electrode water heater has resulted in any difficulties in the operation of this type of heater.

Mr. A. G. Engholm: I think this paper should be brought to the attention of architects, with a view to encouraging them to co-operate with the heating contractors in the construction of buildings such that the future occupants will be able to benefit as regards the heating arrangements.

With regard to running costs, assuming 1 000 sq. ft. of radiation, a heating season of 26 weeks, and the heating on for 6 days a week, 9 hours a day, for a certain building I have in mind the amount of electricity used would be 46 800 units, the amount of coke 17 tons, oil fuel $9\frac{1}{2}$ tons, and gas 1 404 therms. The question which is the cheapest depends upon the cost of fuel. I should be pleased to know whether the authors have worked out any comparative costs on a similar basis.

Mr. William Wilson: There are two questions I should like to ask with regard to Fig. 24, which shows the relative values of various heat-insulating materials. A paper which I once read giving the results of a research on this point led to the conclusion that a material called cow hair-felt was the most efficient insulating packing. The authors mention hair-felt in the text, but do not include particulars in the diagram; what is the drawback that has led to the exclusion of this material?

Fig. 24 is in reality an estimate of the Ohm's law of thermal conductivity for the various materials. One would therefore have expected that the resistivity would have varied with the length of path, i.e. the thickness of the various materials. The relative conductivities for glass silk are apparently as follows: for a 4-in. thickness, 3·8; for half this thickness, 11·1. This indicates that the resistivity does not obey the thermal Ohm's law. The figures for cork are also not in proportion, the divergence being in the opposite direction. For example, for a thickness of 5 in. the relative conductivity is 9·1, for 4 in. it is 10·1, and for 2 in. it is 13·3, so that the first two come closer together than would have been expected. The authors mention that there was a considerable amount of difficulty in getting these data, and it is possible that they are only approximate on this account. If not, I should be interested to know why these peculiar variations occur.

Mr. J. A. Sumner: I agree with Mr. Naylor that water heating is one of the most valuable potential loads to the electric supply industry. The first thing that we have to do is to make water heating "fashionable," i.e. we have to make people realize that it is not a luxury, and is within the reach of everyone; the second thing is to get a tariff that is reasonable. Some mention has been made of the cost at which an undertaking can purchase electricity. Seeing that most undertakings are buying electricity, so far as running charges are concerned, at about 0·2d. per unit, and that an efficient undertaking should only have to add about 0·1d. or 0·12d. per unit for the system losses and certain of the running charges, I think that it is reasonable to say that an efficient undertaking can supply electricity during "off peak" periods at about 0·33d. per unit.

Now electricity for water storage heating at 0·33d. per unit is definitely a financial proposition, provided one has not to buy new apparatus, and I think that once a tariff slogan of "3 units a penny" becomes common water-heating loads will grow very rapidly.

I should like to refer to the need for heat insulation in the structure, particularly of the smaller houses. In the earlier paper* it was suggested that there was some advantage in not having heat insulation, because of the "reservoir" heating effect of the building. A brick building absorbs a considerable amount of heat, and there is therefore a considerable amount of heat available in the building between switching periods; in this paper it is suggested that it is very necessary to insulate the building very carefully. I have in mind a particular case of a house that was built for electric heating. It has brick-cavity walls, and all the downstairs rooms (which are heated electrically) are lined with boards of cane fibre. The windows allow the heat to escape very rapidly and the temperature of the room very quickly drops. On the other hand, the room heats up very quickly, so that the problem arises of whether or not it is economical to switch off each evening.

* *Journal I.E.E.*, 1931, vol. 69, p. 1045.

Mr. W. R. Cox: The specific resistance of the local water has a great bearing on the design of electrode water-heaters, where the water itself is used as the resistance material in which the electrical input is being converted to heat. The paper clearly brings out the very surprising variations of specific resistance found in water from town mains in different parts of the country. This variation may be at least 9:1 when measured at a given temperature. Added to this there is the variation of the specific resistance due to the temperature variations over the working cycle. This will be of the order of 3:1 or 4:1. From these figures it will be seen that a very flexible design of water heater is necessary. The problem is fortunately somewhat simplified by the fact that the resistance variations due to temperature are nearly constant for all varieties of water.

This question of water resistivity has a great bearing on the maximum voltage at which heaters can be operated. The authors suggest voltages of 11 and 22 kV. Water heaters running at 11 kV are possible, at the present state of development, in sizes down to about 750 kW if the specific resistance of the water is high; and at 22 kV from, say, 1 500 kW upwards, again assuming a high water-resistance. Difficulties arise due to the specific loading per cm^3 in the water; if this exceeds a given amount there is a tendency for arcing to start in the water, and this is undesirable. The average water obtainable in England has a relatively low specific resistance, and, except in special circumstances, 6·6 kV seems to be the highest practical working voltage with present designs.

The authors raise the question of the method of rating water heaters. This question is somewhat difficult owing to the large number of variables which occur on different schemes. I am of the opinion that water heaters should be rated on their maximum continuous output. This eliminates most of the variables peculiar to any scheme, and makes it possible for manufacturers to list heater sizes in a form which enables the heating engineer to settle preliminary details of his scheme without spending time in obtaining detailed quotations during the early stages. Water heaters should generally be run at their full output during the whole of the heating cycle, as this enables the most economical size of water heater to be used. The cost of the necessary thermostatically-operated valve is nearly always less than the additional cost of a larger water heater. Considerable space is also saved.

Mr. H. Hooper: When Mr. Grierson was here in 1931 he mentioned that if every domestic user added 1 kW of

load in the shape of a heater it would double the power-station capacity required. Visualizing that, I should like to put forward for the authors' attention and comments the question of the selling of an electric heating system in the purchase value of a house. I do not think the question of thermal-storage service in a house has ever been brought to a practical discussion. I have in mind equipment of 8 to 10 kW capacity which will be required in the average house of 7 to 8 rooms. It must be accepted, when the sale of electricity is being advanced nowadays, that we have to pay for our electricity as we require it. Any domestic apparatus which comes into unlimited use whenever the consumer wants it, and can come on at any period when the peak load of the station is at its maximum, must be charged at a reasonable price which must be included in the domestic tariff. Thermal-storage and other similar consumptions, however, come under a different category. It surely must pay to sell "off peak" units in large quantities if this enables the supply authorities to charge a small proportion on the unit charge, which must be very low if the sale of "off peak" units is to be considered. It is undoubtedly a fact that a big valley in the load curve can be filled up by selling "off peak" units. I have not yet come across a complete small thermal-storage installation which could be sold as an integral part of the building, and I suggest that the manufacturers of such apparatus should design and put on the market suitable equipment. In view of Mr. Grierson's remark about the increase of demand which would result if every domestic consumer added 1 kW of heating load, one can imagine what a tremendous impetus would be given to the electrical trade if thermal-storage apparatus could be installed in a reasonable proportion of the new, better-class houses.

Mr. R. H. Rawll: The paper indicates quite clearly that the vertical type of storage vessel is the more efficient, besides maintaining a better distribution of temperature. In this connection I should like to ask whether the authors have any comments to make on a type of domestic storage heater which came out a few years ago, where the immersion heater was placed at the top of the vessel, either practically vertically or inclined at an angle.

With respect to the authors' figure of 25 gallons of hot water per person per day, some 8 years ago Mr. Milne and I* advanced the view that the time would come when, as far as domestic water heating is concerned, a supply authority would be able economically to charge a fixed price for the heater per annum and to include the current consumed. At that time I was more or less "a voice in the wilderness," and possibly I am still, but I notice that there are already certain supply authorities in this country who have introduced this system—possibly as an experiment—and it is also being adopted with other loads, apart from water heating. It seems to me that people are not going to use hot water in their houses just for the sake of washing. Every supply authority has its statistics of units consumed, and I think it will be found that there is a fairly consistent average of units consumed for any one type of water heater. For this reason I still maintain that one could put forward a fixed price for the hire of a water heater with its maintenance plus its energy consumption. I am not suggesting that the installation charges should be included in this hire charge, as they would obviously vary from house to house. If such a system of charging were introduced, meters would not be required.

Regarding the control of the water-heating load, it is quite obvious that if a supply authority is going to adopt a comprehensive type of control of the load by switching, it must start in the way in which it proposes to carry on in the future. It is of no use starting to switch on by means of superimposed-frequency methods in some cases, and then to find that that method is not suitable in certain other districts; methods must be standardized at the commencement. It certainly seems to me that from a practical operation point of view the local method of operation, i.e. a time switch at each premises, is to be preferred. As far as large installations are concerned, I can see that the cost of local operation by a time switch would be a very small item of expense compared with the total installation costs, but the domestic installation is a different matter from an economic point of view. The extra cost of the time switch, however, in this instance, could be offset by the amount saved on doing away with the meter and the labour of meter reading if my suggestion of a fixed inclusive charge for domestic water heating were adopted.

[The authors' reply to this discussion will be found on page 539.]

Scottish Centre, at Edinburgh, 22nd January, 1935.

Mr. T. M. Ross: Warming by electricity could be very much more pleasant and comfortable to the occupants of buildings where it is applied if something could be done to load the air with a little more moisture than it has at present.

Looking back over the 66 years which have elapsed since I first entered the trade, Perkin's system of high-pressure heating, and the low-pressure systems, seem very complicated compared with the present systems. The advances which have been made since those days go to show that the trade has not been sleeping during the last 66 years.

Mr. D. W. Low: On page 473 reference is made to the design of the insulator or former employed to support the resistance wire in the immersion heater; the authors apparently favour the solid type. While this is satisfactory when the watts per square inch are as low as 10 or 12, I have found that the open slotted type is the better insulator to use with immersion heaters with loadings up to 20 watts per sq. in. The latter figure is what is required to be used in immersion heaters for ordinary domestic hot-water cylinders, as their diameters seldom exceed 18 in. The reason why I think the open slotted type is better will be seen when it is considered how the heat from the element wire is conveyed to the water; the insulator does not touch at any point except that at the bottom of the tube, with the result that all the heat from the element coil has to be conveyed to the tube by means of radiation. In the closed type of former the

* *Journal I.E.E.*, 1928, vol. 66, p. 735.

radiation is restricted, with the result that the temperature of the coil must rise higher than with the open type, and the life of the element is reduced. I have used the closed-type former for many years for immersion heaters for heating oil, where the tube must be of steel. My reason for this course is the same as the authors', namely, to prevent scale from the tube coming into contact with the coil.

On page 464, where particulars of the storage of heat in a building are given, it is stated that the rate of heat loss calculated on the basis of 0·45 watt per cub. ft. is 573 kW; and in practice for a thermal-storage plant of 80 per cent heater and distribution efficiency, and 12 hours' supply period, the daily maximum load would be 1 430 kW. I should like the authors to explain the difference in these figures. I should also like to ask them what minimum size of building they consider suitable for a thermal-storage scheme.

Fig. 22 shows the temperature distribution in a horizontal immersion-heater type of thermal-storage vessel; obviously, with the vertical type of storage tank the heaters can be concentrated more at the bottom, with the result that a more constant variation in temperature is obtained. Coming to domestic water heating, I am entirely in agreement with the authors that the temperature to which the water should be heated should be about 150° F. I carried out experiments in an office building in Glasgow where the hot-water supply was heated by a thermal-storage vessel. Tests were taken with the thermostats set for a temperature of 180° F. and the readings of consumption observed for a week. The temperature was gradually reduced every week, and ultimately it was found that the most economical temperature of the water was 140° F.

Of all the various methods of connecting water heaters the most efficient is to have the heater fitted as near the tap as possible, as in Fig. 31, diagram A. Care should be taken, however, that the draw-off pipe is not very long, otherwise there is a liability of a partial vacuum being created when the inlet cock is shut off. In the early days I had experience with a tank connected in this manner which collapsed for this reason. The figures given in the paper for the consumptions of various installations show definitely that where the pipes are long, a central heater is not the proper one to install, and that the heater should be placed as near an outlet point as possible.

Mr. J. Jamieson: I should like to inform the author that the 2 000-kW garage installation mentioned in the paper is not in the North of England, but is in Glasgow. I support him wholeheartedly in his attitude with regard to smoke emission; if the same stringent regulations were applied to the individual consumer as are applied to generating stations, and if the individual were restricted to a proportionate amount of smoke emission from his chimney, there would be less coal and more electrical heating used, and we should have the benefit of a clearer atmosphere. The figures quoted with regard to coal costs in London show that the supply undertakings are getting usefully from 5 to 6 times the number of heat units that the individual is getting for the same cost.

The authors indicate that the heating engineer is usually called in to discuss the materials of construction for a new building when this is in the embryo stage; my experience is that the heating engineer is never called in until the last moment. I agree with the authors on the importance of heat insulation, and I suggest that they could profitably carry out propaganda of this nature to, say, an association of architects. Such information placed before the architects should be based on figures capable of attainment, rather than hypothetical figures; the figures given in the authors' example are hypothetical. For instance, for a particular roof they claim that by the introduction of heat insulation the sum of £10 per annum would be saved, assuming the outside temperature to be 30° F. I suggest that figures like these should be based on average conditions existing throughout the season, and not on a condition which exists for less than 10 per cent of the heating season. The trouble that arises is that at the end of the year the individual has probably saved £4 or £5, and not £10, and he is not at all appreciative of the fact that the lower saving actually obtained has been due to milder average conditions than were indicated at the beginning. In other words, he is being unwittingly misled. The question of thermal capacity of buildings has been too much neglected in the past; I had expected that the authors would have referred to the case of St. Peter's, in Rome, where the walls store sufficient heat in summer to keep the interior warm in winter without any other form of heating. Turning to the example quoted in the paper of a particular building based on the average of 15 London buildings, the authors in assessing the annual consumption assume a multiplying factor of 2 000 times the installed load; why is this particular figure taken, seeing that on a previous page the figure suggested is 1 600? At any rate, neither of them is correct. In this connection one cannot help feeling that the authors are overstating the revenue to be obtained by the supply undertaking. Where the authors indicate a revenue of £1 100 the supply authority will probably not get more than about £600 at the tariff of 0·24d. per unit.

I agree with the authors that the question of the value of direct panels for heating systems is a highly contentious one, and my own practical experience leads me to disagree with their claim for a 25 per cent economy in fuel consumption for this type of heating. In the section dealing with an assumed installation having a load of 300 kW for direct panels, it is stated that for tubular heaters, disconnected at night, the load would have to be increased by 15 per cent for morning use. Assuming that the authors are referring here to the preheating period, and that the heating period is 12 hours, then an increase of 15 per cent in the load would mean that the preheating period would require to be not less than 5 hours. If we consider the panel heating system on similar conditions to the tubular heating and switch off both at night, and if we assume the preheating period to be restricted to 1 hour, we find that the panels would require to be loaded up to 500 kW and the tubular heaters to over 600 kW. I do not suppose that the authors are indicating that a 180-kW maximum-demand load on a panel system is a better load to the supply authority than a 750-kW load for thermal-storage heating. If, however, that is their claim, then I disagree with them. A tariff for direct panels has to be based on the supply being

taken without restrictions, and at best the supply authority could not hope to get a gross profit of more than 20 per cent; whereas, even taking the figures allowed for by the authors, it would be quite possible for the authority to get a gross profit of 50 per cent on a unit supply for the thermal-storage load. Neither do I agree with their statement of "equivalent hours use" of maximum power; their figure of 57½ per cent with 24 hours' heating is approximately double the correct value. Taking the example given on page 471, we find that the factor in this case of "equivalent hours use" is about 26 per cent, and the multiplying factor of the installed load comes out at 1 100 instead of the figure of 2 000 used by the authors. As regards the question of 2-part tariffs, my sympathies are all with the supply authorities, who are subjected usually to more kicks than praise. Direct panel heating is an unrestricted load, and cognizance must be taken of that fact, and of the load factor of the heating load offered, when fixing tariffs.

I am surprised to learn that the authors have met with trouble in the connecting cables of immersion heaters and electrode boilers. I have never yet met with any trouble of this sort, and I think that the cable manufacturers are to be congratulated on the excellence of their workmanship. On page 479 the authors state that the consent of the Electricity Commissioners is always required before electrode boilers are installed. This only applies, however, to an e.h.t. supply. I should be interested to know whether the relative values of heat insulation of materials given in Fig. 24 have been checked by the authors, because I have never found the actual values to coincide with those given in this graph. In Table 16 it is stated that the average consumption of hot water per head per day in an English hotel is 20 to 25 gallons. I should like to know whether this represents purely direct personal requirements or whether it is supposed to cover the individual proportion of the total volume of hot water required in the building. If the latter, then the figure is several hundred per cent in error.

Mr. W. J. Cooper: I am glad that the authors refer to the suggestion that we should support the selling of heat on the basis of a fixed number of B.Th.U. per £. This method would eliminate a great many difficulties when making comparisons. I am aware of one or two cases where the requirements have been specified as B.Th.U.'s of heat, and where different firms have submitted greatly differing quantities of units to derive that heat. There thus arises in the mind of the probable consumer the question why such differences should occur between experts because of the difference in cost per unit when the differing quantities of units are related to an assumed cost per annum expressed in pounds sterling. What we shall have to do is to get the supply authorities to supply controlled requirements at a contracted amount per week, per month, or per annum.

Mr. E. Seddon: I am glad to find the authors advocating the heat insulation of buildings, for, whatever form of heat is used, a definite saving in annual costs must result if buildings are suitably treated so as to avoid undue waste from radiation.

Another point in the design of buildings is that sufficient attention has not been given by architects to ventilation, particularly in domestic property. The advocates of coal- and gas-fires stress the ventilating qualities of those forms of heating, but I very much doubt whether these methods do more than change the air at floor level. The ideal arrangement would be to have ventilating ducts rising through the house, with connections to the ceiling of each room.

On page 465 reference is made to a daily load curve of the Bedford undertaking: I should like to have some information regarding the time-controlled heating load. I assume that the curve for the 18th November is compared with that for the 5th February, the former not having the special heating load which was evidently connected before the 5th February. There seems to be practically no change in the morning load between the two curves, whereas all the change appears to take place in the evening, the load being extended for about 2 hours.

For room heating I think there can be no doubt that a well-distributed low-temperature system is the most satisfactory, and in the treatment of existing property a tubular installation will in general be found to be the most economical. Rooms up to 3 000 cub. ft. can be suitably heated for average conditions by single runs of 60-watts-per-foot tubing to give a loading of 1 watt per cub. ft., though in very cold weather when the temperature is at 32° F. it will be necessary to supplement the tubing by the heating element of a fireplace radiator which is normally used for giving fire effects without heating.

I should like to ask the authors whether the dusting effect of wired paper has been overcome, as I notice from page 470 that the loading of the latter is now 18 watts per sq. ft., whereas formerly the figure was 22 watts per sq. ft. In one installation of this sort which I know of, the ceiling has to be re-whitened every 6 months. If the lower loading will now get over this difficulty, I cannot imagine a better system for new property.

The paper deals more particularly with the heating of large buildings, and comments on the rates of charge offered by supply authorities. I should like to know whether the reference at the foot of page 471 is to untransformed energy with restricted periods. In Edinburgh we can offer 960 high-voltage units to the £ for thermal-storage night supplies and with a 2 hours' boost at midday. A few consumers take low-voltage supply at 0·3d. per unit during restricted hours for the same purpose.

Mr. N. C. Bridge: I regard the question of ventilation referred to by Mr. Seddon as a very important point indeed, and in another paper of this nature I hope that greater space will be allotted to the air-conditioning and ventilation of buildings. Although we are told, for instance, that almost half as much energy as for warming is required for the air-conditioning, there does not seem to be any indication of the energy requirements for the diffusion of this air to the best advantage. In connection with the heat insulation of buildings, can that not be overdone? Should we not make some allowance for the buildings "breathing," so to speak, as well as the people inside them?

In connection with the question of the supply for heating, I have with me an extract from my Chairman's Address to this Centre, which I gave in October 1933; I should like to read this again now, since owing to

limitations of space it was not reproduced in the *Journal*. I then said: "If, in defiance, maybe, of domestic economics, or, say, on the grounds of hygiene, cleanliness, and labour-saving, electric heating as at present generally applied became as widely adopted as electric lighting, we might conceivably, in the fear of an intensive cold snap just before Christmas, have over again that economic impasse that so often has resulted in the past from the too exclusive cultivation of the lighting load—new plant rushed in to meet the peak demand, fixed charges up accordingly, and development arrested quite artificially. Heating could conceivably become by far the largest factor in consumption, but we do not want it merely as a peak in wintry weather. It would seem most desirable, on this account, to offer every encouragement for the development of storage methods, not only for water heating and cooking, but for house or room heating also. Such heating in any case is not only a matter of transient personal comfort; it is a matter almost of necessity at times in a climate such as ours for the preservation in good condition of property and household effects." Following upon this, it may possibly be of some interest to mention that in the west of Scotland this winter the temperature was about 10 deg. F. above the average for the latter part of December, and on that account the maximum demand anticipated did not materialize to the extent of some 30 000 kW. The effect of a drop to 10 deg. F. below the average seems a little alarming to contemplate, with our present plant capacity!

Mr. F. C. W. Clark: I should like the authors to tell us the relative advantages of controlling the load of steam boilers of the electrode type by means of variable electrodes, as against control by means of a magnetically-controlled blow-down valve. The latter always appears to me to be a rather inefficient way of load control, as the water is heated and then discharged into the hot-well tank, where the heat is lost. Would it not be better to place the magnetic valve in the pump delivery pipe and so control the input water of the boiler by bypassing the feed water back to the tank as the load rises?

Fig. 24, which indicates the efficiencies of various heat insulating materials used for boiler laggings, gives no figures for hair and wool felt, although these are in common use. Have the authors any figures which they can give for these materials?

Prof. F. G. Baily: The whole question of the electrical heating of buildings depends on the price at which electric energy can be sold for this purpose, to meet the competition of other fuels—coal, coke, crude oil, and town gas—all of which can produce the same ultimate effect when suitably used. Electric heating lacks the conspicuous advantages that the electric lamp or the electric motor possesses, and in consequence the price for heating has been put down to a much lower figure than that for either lighting or power. It appears to me, however, that this figure cannot be maintained, if the house heating load becomes an important part of the total demand. The authors put forward a load factor of 33 per cent for large buildings, which assumes that the building is kept warm continuously, even over the week-end, and that the maximum load is caused by an outside temperature of 30° F. The winters of recent years have caused us to forget what a really hard winter is like, and that a succession of hard winters can occur. Moreover, as these same conditions prevail all over the country the demand will be universal. Under such conditions the maximum demand will be substantially increased, with an almost corresponding decrease in the load factor. It is well also to realize that the private house, a very much larger possible load, will have a lower load factor, and probably a much lower one. The very facilities of electric heating will permit of a large maximum and an economical average. Very cold weather occurs but seldom, and the expense of keeping the house warm will therefore be small, while advantage will be taken of the frequent mild days in the 6 colder months. The daily load factor may look highly attractive, but I believe the yearly load factor will range from 20 in South Scotland down to 12 in the south-west of England. There will be little diversity factor to keep down the denominator, for in very cold weather everyone will put on full heating all day long, and use portable radiators to supplement the normal appliances. Load factors of this order make the item of capital charges important: thus with a load factor of 16 per cent the capital charges on station plant and distributing mains come out at 0·3d. per unit, even allowing for a future cost of only £26 per kW of demand, and less than 7 per cent charges on capital. It will be difficult to maintain a selling price of 0·5d. per unit for such a load, if it is large enough to require equipment to deal with it. At present it is excused a good deal of its proper costs because it is small, and it is really in the position of an advertising item, not expected to be directly remunerative. A large increase, if the load factor is not improved, will make little difference to the total cost of its production per unit, and the financial aspect will become precarious.

Mr. J. Gogan: On page 463 the authors refer to the value of heat insulation to the structure; as the paper refers to the electrical warming of buildings it may be considered by the uninitiated that the special treatment of buildings with heat-insulating material is only necessary when buildings are heated electrically, whereas it applies equally whether the buildings are heated by gas, oil, or any other method. I thoroughly agree with the authors that the value of heat-insulating materials should be carefully studied by architects, as it has been proved from structures erected in 1927 that in this way considerable saving can be effected in heating costs.

At the bottom of page 471 the authors suggest a "day" and a "night" rate, namely, a day rate of 0·75d. per unit and a night rate of 0·5d. per unit. The load factor for this class of load works out at $13\frac{1}{2}$ per cent, and I submit that no supply undertaking could afford to sell current at the rates stated with such a low load factor. I should like to know on what basis these figures were arrived at. I admit that one could sell electricity at night time only at exceptionally low rates, but to sell at night and day at the rates stated would not be an economical proposition.

Referring to the temperature at which domestic hot-water supplies should be maintained, I consider the setting of the thermostats at 150° F. to be too high; 130° F. has been found to be more successful.

[The authors' reply to this discussion will be found on page 539.]

North-Eastern Centre, at Newcastle, 11th February, 1935.

Mr. R. W. Gregory: I am a great believer in low-temperature ceiling-panel heating. It is efficient, as there are few convection losses. It is perfectly clean, as there are no convection currents to raise the dust, and it does not interfere in any way with the walls and furniture of a room or office. The popular notion that ceiling-panel heating warms the head and not the feet is not supported by actual experience. According to Dr. Oscar Faber, who recently published* a set of curves showing the vertical temperature gradient in rooms with various methods of heating, the difference in the temperature readings at 1 ft. and 8 ft. high with ceiling panels is not more than 1·5 deg. F., while with exposed steam radiators it is nearly 20 deg. F. Nothing gives one colder feet than the floor draughts produced by a coal or gas fire. Architects will not specify low-temperature ceiling-panel heating with embedded water pipes because they fear cracks in the plaster ceiling. My own experience with this system, however, has been extremely satisfactory; I have met with no ceiling cracks which can be attributed to the use of the heating panels. According to the paper the ceiling-panel system of heating shows 25 per cent fuel economy over convection systems of heating. Thus, since both the desirability and the efficiency of the ceiling-panel system have been established, the problem before the industry is to settle how it can be carried out electrically.

It would appear from Fig. 2 that one can obtain a rough comparison of the number of units consumed by the various systems by multiplying the maximum kW demands on the mains by the number of hours during which the electricity is used. If this is correct, then the invisible hot-water ceiling-panel system with a maximum demand on the mains of 750 kW can be reckoned as using 9 000 units (750×12), as compared with 4 320 units (180×24) for the low-temperature electric ceiling-panel system working on room thermostats. I expect that the latter figure is in practice considerably reduced, but on this showing the number of units consumed by the latter system is less than half that consumed by the former.

If, therefore, electricity can be supplied for general heating at ¼d. a unit for the 12 off-peak hours and ¾d. per unit for the 12 on-peak hours, then the daily electricity bills for the two systems will be approximately equal, as is shown below, whereas the demand on the system will be considerably less in the case of the low-temperature system with thermostatic control. The bills will be as follows:—

Thermal storage:	9 000 units at ¼d. per unit =	2 250d.
Room thermostats:	2 160 units at ¼d. per unit =	540d.
	2 160 units at ¾d. per unit =	1 620d.
		2 160d.

The continuous thermostat-control system should, I think, provide better comfort for the inhabitants of rooms and offices, as it takes care of the day variation in temperature, the heat produced by the occupants themselves, the heat produced by the lighting, and the thermal storage of the building and its contents. In a room occupied between 9.0 a.m. and 6.0 p.m. the heating would, on most days, be automatically switched off during the afternoon system peak.

* *Architects' Journal*, vol. 81, p. 131.

What really matters to the ordinary man when considering alternative systems of heating, is whether he can obtain from the use of electricity advantages which are worth the essential extra cost of such heating, and it is because of this that I think the future of all-electric heating for dwelling houses and offices will depend very largely upon the heat insulation provided in such buildings. If, for example, to heat a certain building costs £20 per annum with coke-fired boilers and £60 per annum with electricity, the extra £40 incurred by the use of electricity might not be worth spending, but if by careful insulation of the building the consumption in B.Th.U. is reduced by half (not an impossible figure), then the costs involved will be £10 and £30 respectively, which means that the advantages of electricity only cost £20—a figure which might be well worth while. Reasonable insulation of a building costs about 2s. or 3s. per square yard extra on the outside walls, roof, and floors, and this extra is well justified by the saving in fuel costs, even if electricity is not used.

The authors draw attention to roof and ceiling heat-losses: I should like to draw attention also to the losses on ground floors of dwelling houses. The space below the ground floor is ventilated by air bricks, and can be taken as being at about the outside temperature. A ¾-in. floor board will transmit about 1 B.Th.U. per sq. ft. per deg. F. difference in temperature, a figure 3 times as great as that for a 9-in. brick wall plastered inside. If one fixed below the floor boards a ¾-in. layer of Tentest or Celotex, the heat transmission would be reduced from 1 to 0·32 B.Th.U. per sq. ft. per deg. F.

Some years ago Mr. Grant and I were considering the possibilities of obtaining the high efficiency and comfort of ceiling-panel heating without the expense of using embedded panels, and we thought this could be obtained by projecting radiant heat from a radiator of the reflector type on to the ceiling itself. This system would appear to have some advantages if used in conjunction with indirect lighting. Many rooms nowadays require as many kilowatts for lighting as for heating. If, therefore, indirect methods of lighting and heating were adopted, as shown in Fig. H, the switching-on of the lights would normally switch out the heating if the room temperature were controlled thermostatically.

As regards air-conditioning, in this country where atmospheric conditions are such that one rarely experiences discomfort in a reasonably heated room, the cost of installing and running an air-conditioning plant will prevent its being used extensively for individual houses or even for blocks of residential flats when the latter are built in quiet residential districts. On the other hand, as long as our city streets remain noisy and our city air is foul and dirty, i.e. until the complete electrical age arrives, there will be a growing demand for air-conditioning in office blocks. The demand already exists in places where people congregate in crowds and where the day consumption of lighting energy is large, i.e. in cinemas, theatres, and big stores.

In office blocks the main requirement is silence. This means permanently-closed windows, and with this condition some form of forced ventilation and air-conditioning is essential. I gather that if the air circulated through a building is used for heating the building, then it is found necessary to heat up the air to a temperature considerably above the 60°–64° F. considered comfortable by human beings. If, however, ceiling-panel heating is used as the main source of heat, then the temperature of the circulating air can be reduced to a figure considerably nearer 60°–64° F. For office buildings where, owing to the lack of crowding, the amount of air necessary for ventilation is small, a considerable economy should be obtained by the use of ceiling-panel heating combined with air-conditioning.

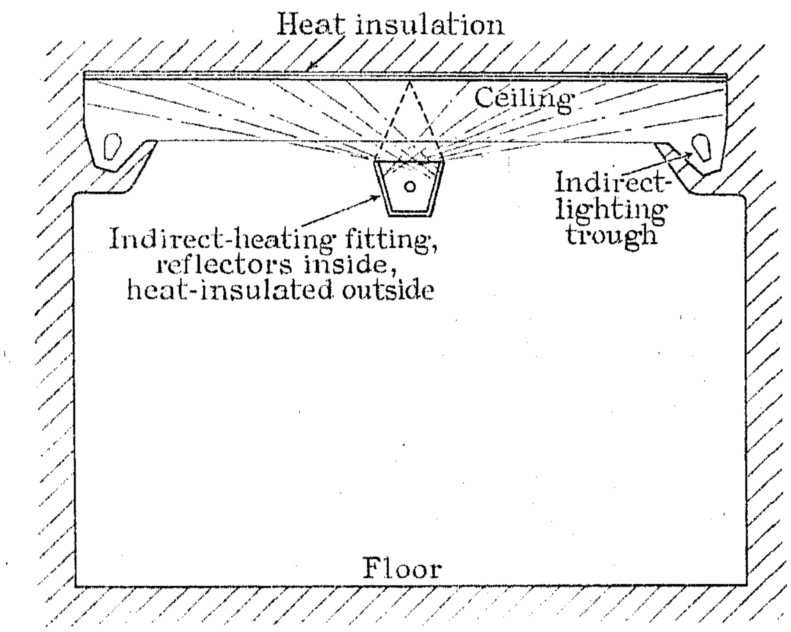


FIG. H.

Mr. R. W. Cairns: After seeing the authors' lantern slides of so many central-heating and hot-water supply installations heated electrically, one cannot help feeling that in this area we are rather backward from the point of view of installing this type of equipment.

I agree with Mr. Gregory that a very considerable saving in fuel costs would be obtained if only architects would pay more regard to constructing buildings in a manner that would conserve heat instead of dissipating it. Recently I was asked to estimate the cost of central-heating the top floor only of a large garage in this city; I found the cost to be equivalent to that of heating the remainder of the garage, which had approximately four times the cubic content. This was owing to the type of roof construction employed, which had no doubt been adopted in order to reduce the capital cost, but it involved a heavy capital cost for the heating installation, and also a continuous heavy yearly cost in fuel.

One is frequently asked the cost of installing an electrically-heated domestic hot-water supply in an existing building, and it is necessary to give very careful consideration to the question whether it would be good salesmanship to recommend it. I frequently hear people say that a coke boiler is not a labour-saving appliance; no doubt electricity is ideal from a labour-saving point of view, if only it can be obtained at a price to suit the pockets of the householder. The ordinary householder is apprehensive of what his costs will be if he accepts electricity as the heating medium, and I feel that supply undertakings could do much to relieve his fears. Supply undertakings have a large field in supplying domestic hot-water and cooking facilities. I am convinced that a scheme could be worked out of providing the householder with sufficient electricity for his reasonable demand at a fixed amount per quarter. He could then decide whether this sum was worth all the convenience he would obtain by using electricity.

No doubt the obstacle to an electric hot-water supply, or any hot-water supply heated by other than solid fuels, is the ordinary bath, which requires 30 gallons of water at 105° F. each time it is used as a hot bath. Modern bathrooms are not suited to the purpose for which they are intended, and I am surprised that better sanitary fitments have not been adopted in the huge housing schemes now under construction. A bathroom in a small house should have neither a bath nor a wash-basin, as we know them. An ordinary bath is useless for bathing a person engaged in a very dirty occupation; the only intelligent way for such a person to bathe is by means of a shower bath, as is done at all pit-head baths. A shower only uses approximately 5 gallons of hot water per bath, and the user has the added advantage of being able to cool his body by reducing the temperature of the water, and obtaining the refreshing effect a bath should give. Instead of a wash-basin in the bathroom, I suggest that running water be used, by fixing a mixing valve in the shower recess. The base of the shower bath should be a white, glazed, deep sink, which could be used for bathing small children. If this were the modern bathroom equipment, the quantity of hot water used would be reduced to one-fifth of the existing figure. Everyone would then be able to have an electrically-heated domestic hot-water supply at a cost he could afford, and supply undertakings would have no excuse for refraining from giving a supply at a fixed quarterly charge.

Mr. K. M. Mackenzie: Regarding the last speaker's remarks about a fixed charge for a fixed quantity of hot water, although it may not be possible to provide an unlimited supply of hot water it is possible to gauge an adequate supply for a given house within fairly wide limits. The question that arises is the automatic method of confining the supply for water heating to off-peak periods. There have been numerous suggestions as to how that can be done; one method utilizes a thermal relay in conjunction with a contactor which automatically brings the electric water heating on at night and also at those periods during the day when other heavily loaded electrical services of the house are off. Such a scheme renders it unnecessary to meter for water heating, because it enables the supply authority to estimate with fair accuracy the units for 12 months, and therefore to fix an equitable tariff, and a lower one than that which operates now. It may be that area metering would be necessary, but certainly not the metering of individual consumers.

Mr. G. E. Marden: Can the authors state the maximum life of the immersion heaters that have come under their control, and also whether these heaters were those with insulating formers having totally enclosed resistance

spirals? I should expect heaters with insulating formers having an open slot (the wire being only air-insulated from the container tube) to have the longer life, as with the resistance wire totally enclosed by a wall of insulating material—as preferred by the authors—the wire operates at a higher temperature, and consequently the life will be reduced.

With regard to electrode heaters, the authors detail the various designs now available having the electrodes inserted from either the top, bottom, or side, of the shell; provided all other conditions are equal, and unlimited space is available, which type do they prefer, and for what reasons?

Referring to the question of the nature of the water used for electrode-heater installations, Mr. Grierson in his introductory remarks made special reference to a recent experience where it was found that the water was of too low a resistance, before any salt had been added. I should be glad to know of the steps taken to correct the resistivity of this particular water.

Mr. H. Leyburn: The heading "Automatic Overcurrent Protection for Groups of Immersion Heaters" on page 481 is rather confusing, since in this sub-section the authors discuss the protection of both immersion heaters and electrode heaters. Although I agree in the main with what is said about immersion heaters, I consider that the difficulties they suggest in connection with earth-fault protection for electrode water-heaters are largely non-existent. There is little difficulty in providing such protection by utilizing either the "spill current" flowing in the secondaries of three star-connected current-transformers, or, alternatively, the current flowing in the secondary of a core-balance transformer; and, further, the protective gear can be so designed that it will not operate on what the authors term "foreign earths."

Water heaters are most conveniently subdivided into three ranges, and I suggest that the protective gear should be so chosen that each range is protected adequately on an economic basis, bearing in mind that inadvertent tripping or damage of large heaters is more serious than that of small heaters. The three ranges, and the protective systems that I consider to be most suitable for them, are as follows: (1) For immersion water heaters up to 200 kW, overcurrent and earth-leakage protection, the latter being instantaneous. The danger of inadvertent operation due to external earth faults does not arise with immersion heaters. For very small heaters of this class overcurrent protection by means of fuses would probably suffice. (2) For electrode water-heaters between 200 and 750 kW connected to low- and medium-voltage systems, the overcurrent protection should be similar to that referred to in (1) above; but earth-leakage protection should be provided by means of an induction relay having an inverse and definite minimum time-limit characteristic to ensure that the heater is disconnected quickly on an internal earth-fault but that the time-lag on an external earth-fault is so long that the network protective relays operate first and disconnect the fault, leaving the heater itself in commission. The small additional cost of an induction relay is amply justified on heaters of this size, in view of the increased reliability in service and the improved protection against internal faults. (3) For electrode water-heaters above 750 kW connected to systems of 6 600 volts and over, the earth-leakage relay referred to above should be replaced by a directional relay energized from the current-transformer "spill current," and from the "open delta" voltage derived from a voltage transformer. This type of protection provides instantaneous clearance of internal earth-faults and does not respond at all to external earth-faults, and in view of the greater importance of these large heaters the small additional expense is again justified.

On pages 483 and 485, the authors refer to "unbalanced-phase protection." In my opinion the overcurrent and earth-leakage protection enumerated in (1), (2), and (3), above is all that is required, and the provision of unbalanced-phase protection would introduce unnecessary complication and expense. I should like the authors to give particulars of the unbalanced-phase protection they have in mind, and also their reasons for preferring this type of protection to earth-leakage protection, which, after all, is simpler, more economical, more robust, and guards against earth currents, which are more dangerous and undesirable than unbalanced-phase currents.

Mr. T. Ritson: The authors state that heavily tinned, solid-drawn steel tubes give satisfactory service as immersion-heater containers. Is the "tinning" pure tin, and is it applied inside as well as outside? If the tinning is inside, how does it withstand the temperature conditions? Rusting of the inside of the tube is mentioned; have the authors not experienced such severe rusting or scaling as to make these tubes unreliable? Other experience shows that steel is unsuitable, as it is subject to both rusting and scaling. Tilting of the container tubes is recommended to drain out moisture. Is this worth while, seeing that during service it will be vaporized? Have expanded-in tubes any advantages over screwed-in containers when one is making up banks?

The authors mention that in soft-water districts gun-metal face plates are used. Are steel tubes used with these face plates, and, if so, are they expanded in? If they are expanded in, it would appear that such a joint would be far from satisfactory.

With regard to the question of closed versus open slots on the immersion-heater element formers, while the closed-slot type has certain protective advantages does it not tend to shorten the life of the element by increasing its working temperature?

Have the authors any experience of the effect of the distance of the element spiral from the container tube upon the working temperature of the element?

I agree that single-phase heater units are to be preferred to 3-phase units, and this can easily be appreciated if one considers that, using a 12-slot former, with a 400-volt 3-phase delta-connected winding the maximum voltage-difference obtainable between adjacent spirals is 200 volts; with a 230-volt series winding it is 115 volts; and with a 230-volt parallel winding it is about 80 volts.

It is well known that long life of an element results from a low watts loading of the container tube; the authors give 15 watts per sq. in. as a maximum, with 10–12 watts per sq. in. as a normal figure. What is a

reasonable life for this loading? This value of 15 watts per sq. in. applies, of course, to storage systems in which the water is never changed (with the exception of the addition of make-up water), and once the temporary hardness is removed no more scaling will be experienced on the containers. In local domestic heaters, however, the water is continually changing, and the scaling of the containers is consequently accumulative. Have the authors any experience to determine the watts loading which should be employed in this case, and do they know what length of life can be expected from the heater element?

Mr. W. A. A. Burgess: I should like to know what particular merit oxalic acid has as a corrective agent for lowering water resistance. It is a poison, and there must therefore be some special reason for its use to offset this drawback.

The heat insulation of buildings is admittedly advantageous in reducing total heat input, but this is common to all methods of warming and, while it should be kept in mind and advocated as a rational procedure, it is not a fighting point for electricity against other means of warming. The effect of windows, either open or closed, upon the heat insulation of a building is so marked that the actual results in cost of electricity for heating a modern well-lit and well-ventilated house or building are apt to be disappointing in comparison with those of a less modern building upon which little or no expenditure for this purpose has been incurred, or where windows were normally kept closed.

I agree with the authors that heat insulation should receive attention in all new buildings, but it should be considered by the architect as relating to the total heat dispersion of the buildings, and not left to specialist heating contractors as a corrective. The case of existing houses and buildings is different; the whole effort is here to be made by the heating engineer and the supply authority. In most cases it is the latter, and he is to consider if it is worth his while to load up the capital costs by recommending heat insulation, knowing that it will reduce the consumption of electricity if efficient, and having no direct measuring device to go by or any means of proving that his recommendation is worth the cost. It is not surprising in the circumstances that supply engineers leave heating insulation alone except to use lack of it as an excuse for high consumption of electricity.

[The authors' reply to this discussion will be found on page 539.]

East Midland Sub-Centre, at Derby, 26th February, 1935.

Mr. F. H. Pooles: It is interesting to note that electrical heating has been installed at the offices of the Royal Institute of British Architects. This fact will certainly assist in breaking down the prejudice against electrical heating that exists among architects, many of whom consider that it is too expensive for consideration. The authors have proved that there is a definite case for electrical heating, given the correct tariff, and that unlimited developments await the undertakings that will offer off-peak load at a competitive price.

I should like to ask whether the type of immersion heater fitted with controlled rotating elements is likely to prove more successful than the fixed type. From the slides shown, the former seems to be more adaptable for variation of loading and temperature control, and it should require simpler and consequently less costly switchgear.

The insulation of heating systems, especially of the domestic type, should receive more attention. The radiation losses due to unlagged tanks and pipes have been the cause of the failure of many installations which, with a little forethought, would have proved quite successful. Tests carried out on quite a small unlagged domestic water-heating installation showed that the losses amounted to six units per day; this is a luxury for which the smaller householder cannot afford to pay.

Mr. J. Messent: There is great difficulty in applying thermal storage to an existing building, and I wish to ask the authors whether they consider that such cases can be met to any extent by local thermal storage, somewhat on the lines mentioned in the paper, but possibly developed farther. Makers of tubular heaters are at some pains to reduce the heating time-constant, but it could easily be increased greatly if this were advantageous.

The geographical distribution of the plants illustrated by the slides is significant; most of them appear to be in London or Manchester. Is there some reason for this?

The load curves showing the effect of weather on heating load are calculated to frighten station engineers, but it should be noted that these relate to central areas where the fires, etc., are mainly in offices. Inset electric fires in bedrooms of a residential district show a very different effect, as they form a definitely off-peak load, coming on early in the morning and late at night.

The authors have done a great service in pointing out the inconsistency of the opponents of electric heating in contending on the one hand that it is wasteful of fuel and on the other asking the Government to insist that, in the interest of the mining industry, all new houses shall have chimneys in all rooms. If electric heating wastes fuel, it must be the miner's best friend.

Mr. W. F. Furse: I am very surprised to find that the authors do not consider cooling and conditioning of air to be a large potential load for station engineers, because I think all underground offices and cafés should be interested in this subject.

I agree with the authors that before much progress can be made the supply industry will have to quote lump sums per annum for electricity for domestic hot water, for the heating of certain types of building, and for other services. The capital cost of the equipment will, of course, enter into this problem, but the running costs will be the deciding factor.

The authors' figures for the pipe losses in domestic installations where hot and cold water are laid on to the various rooms are useful, as it is known that these losses are very heavy indeed, and if electricity is used for central heating under such conditions the consumers are bound to be disappointed.

Mr. F. Nicholls: The advantages to the supply authority of thermal storage are undoubtedly very great. The installations of this sort shown in the authors' slides have proved successful from the point of view of cleanliness and ease of operation; they have also enabled supply authorities to give terms which have rendered such installations not only cheap to operate but of very great satisfaction to users.

A large number of architects are, however, not yet convinced that electrical storage heating is a paying proposition. This is an obstacle, and more especially so in the Midland Counties where coal can be purchased at 13s. to 14s. per ton. The opposition of architects is, however, being gradually broken down.

The authors refer to the 2-part tariff meter, and also to the possibility of supplying current at ¼d. per unit after 7 p.m. To the consumer this is obviously a very attractive proposition, so much so that one can quite easily conceive that a new peak may be created in consequence.

I am very interested to note that the authors advocate 400-volt supplies to immersion heaters up to a rating of 200 kW. Farther on in the paper it is stated that there are even larger installations—up to 1 000 kW—operated at 400 volts. I feel that this practice is very desirable in view of the fact that it keeps down the cost of switchgear. Perhaps the authors will give us more particulars regarding the cost of covering an immersion-heater vessel with cork or some other similar material.

I am pleased to note that they suggest a temperature of 150° F. for domestic hot-water supplies. No doubt this figure has been arrived at in the light of experience. In Derby we are very fortunate in this respect, in that with a temperature of 170° F. we experience practically no trouble. I think the authors will agree that the higher the temperature at which one can operate the domestic supply the better, from a thermal point of view.

[The authors' reply to this discussion will be found on page 539.]

Mersey and North Wales (Liverpool) Centre, at Liverpool, 11th March, 1935.

Mr. O. C. Waygood: The authors refer to very low rates obtainable for electricity, but it should be made perfectly clear that these rates only operate over a restricted period. It may be of interest to mention that in the retail trade the total number of units used per annum is approximately 140 millions, that the price paid per unit varies from 3·38d. down to 0·88d., the average being 1·27d., and that the maximum demand is close on 18 000 kW. It would not be an economical proposition for those consumers to think of electricity as a means of heating a building.

In Fig. 2 the authors suggest loadings for various methods of electric warming. If these loadings are applied to the prevailing charges applicable during the normal working period, it will be noted that the running costs would react against the use of electricity. This is confirmed if typical examples are calculated from Figs. 3, 4, and 5. These graphs are very useful, and I suggest that the value of the paper would be enhanced if the authors would add as an appendix a typical case comparing electricity, oil, coke, and gas.

Another point which should not be overlooked is the space factor. Am I correct in assuming that electrode boilers occupy far more space than the corresponding equipment for coal, coke, or gas?

Mr. J. Jamieson: With reference to Mr. Waygood's remarks, I can assure him that he could get very low tariffs in Glasgow; in fact it is possible to obtain with the commercial service tariff a running charge of ⅜d. per unit, which will, in the coming year, be reduced to 0·3d. per unit.

Mr. Waygood also referred to Figs. 3, 4, and 5. There is undoubtedly every opportunity in connection with these graphs to obtain erroneous results, owing to the fact that they are based on conditions which exist for only 5 per cent of the heating season. They would be of more value if they were based on average conditions, and this applies irrespective of the fact that values of 57 per cent and 35 per cent have been given for certain conditions. It has been shown that these latter values referred to are incorrect. If one refers to the practical example cited on page 471, where the annual consumption is stated as 21 777 units, and if one applies the graph on page 468 to this particular installation and makes all the necessary allowances and corrections for the particular installation, and also takes the best possible efficiency, one still finds that the answer is about 70 per cent too high. I have personally been working for some time past on a graph which would give for this particular installation an estimate of 21 940 units.

I am sure that the authors could prepare a graph, based on proper conditions, which would be of vast help to the industry, and I suggest that they aim at a single graph.

In spite of the fact that to-day we are getting cheap rates with as little as 2 hours' restriction throughout the 24 hours, thermal-storage applications are still of vast importance to the supply undertaking. If the latter can get an off-peak load, this will in every instance help to improve the station load-factor. The authors showed a slide relating to the Elmwood Garage, Halifax, and it may be of interest to them to know that in that particular case the increase in the load factor on the station amounted to 1½ per cent. With the ordinary efficiencies at which stations are running to-day, it is found, I believe, that an increase of n per cent in the load factor decreases the standing charges by the same percentage. This shows the advantage of thermal-storage installations to a supply undertaking.

Mr. G. E. Swift: With regard to tariffs, if one is unable to give a low rate for heating and, as an alternative, quotes an "all-in" tariff, does not this penalize the heating tariff by setting it with the higher-rate services?

In connection with heaters taking a supply from a local transformer, would there be any advantage in having electrodes supplied at low voltages of the order of 100 volts?

It is stated that care must be taken in selecting the position of a thermostat. I should like some information

as to how to arrive at the definite position for the thermostat in a vessel.

With regard to ripple switching by tuned relays for controlling off-peak loads, would the increase in cost be appreciable if such apparatus were used for one installation?

Mr. C. R. Bolton: With reference to the displacement type of low-pressure water heater, illustrated in Fig. 31, the authors say that this system is unsafe unless a safety valve is fitted, owing to the fact that scale is liable to choke the vent pipe where it is teed on to the draw-off pipe. It should be pointed out, however, that this is bad practice. A vent pipe should not be used for draw-off purposes, but should run direct without any further connections, so as to rise over the top of the feed tank.

In connection with electric heaters generally, I should like to ask the authors whether they have ever experienced trouble where nichrome is used in contact with asbestos, and, if so, whether they can offer any explanation.

The Authors' Reply to the Discussions at London, Manchester, Birmingham, Edinburgh, Gloucester, Leeds, Newcastle, Derby, and Liverpool.

Messrs. R. Grierson and **D. Betts** (*in reply*): Consideration of the discussion clearly indicates to us that the objects of the paper, i.e. "the interchange of views with fellow engineers engaged in solving similar problems and also different aspects of the same problem," has been accomplished beyond our most optimistic anticipations. Our sincere thanks are due to over 80 speakers for the time that they have expended on the paper and also for the very friendly and courteous reception that has been accorded to it and to us at the various Centres.

In order to economize space, we have adopted the course of replying to the various points raised under the appropriate sections and we trust that this course will be acceptable to our critics.

The Economic Practicability of Electrical Energy as a Source of Heat.

Several speakers have referred to the apparent iniquity even of discussing the use of electrical energy as a source of heat, but we submit that this aspect of the subject is beyond the scope of the paper, as we clearly indicated in the original title and in the introductory note. Essentially, the paper deals with the method of execution, the principle having already been accepted for reasons which are not material to the present discussion.

We must join issue at once with Mr. Waygood, when he remarks that it would not be an economical proposition for the retail trade to *think* of electricity as a means of heating a building. This, for the reason that in the larger stores the heat emitted by the elaborate lighting equipment frequently approximates to the maximum heat requirement of the building during the prevalence of severe weather, and the heat from the lighting equipment plus customers, in a popular store, very frequently exceeds the maximum heat loss of the building.* Under these circumstances, even a direct electric warming system, under local thermostatic control, will provide an off-peak load and will therefore qualify for a special all-in rate, generally as indicated on pages 462 and 469 of the paper.

Heat Insulation of Buildings.

This section appears to have created greater interest than any other single item in the paper, and it is undoubtedly of vital importance, as it very materially affects the efficiency of the heating installation, i.e. the quantity of heat required to maintain under given weather conditions a given condition of comfort in a building.

Dr. Griffiths suggested that additional information should be included in the paper, but this is not possible on account of restriction of space. The location of the insulating material, i.e. on the internal or, alternatively, on the external surface of the walls and flat roofs, has a marked effect on the thermal capacity of the building and on the response of the comfort condition to the supply of heat, and care must obviously be exercised in taking decisions for different types of buildings. A note of warning might be sounded here regarding the fallacy of the heat-insulating properties of cavity walls of the ventilated type, for if there is a free flow of air through or within the cavity, it has the effect of materially reducing the thickness of the wall and hence the heat-insulating properties of the wall. In order that air may be employed as an insulator, it must be held motionless, as it is in the interstices of cork, magnesia, molar brick, and other heat insulators.

Mr. Cox, in the London discussion, directed attention to the serious loss of heat that takes place through single glass windows, and also to the tendency of the modern architect to use glass much more extensively than hitherto, regardless of the effect on the annual fuel bill. Double windows are one solution of the problem, and in city buildings they have a most beneficial effect in the direction of the reduction of traffic noise within the building, but they are costly to install and to maintain, i.e. clean and paint.

Mr. Mallinson, in referring to the matter, dealt with roof construction and emphasized the improvement effected by making the roof wind-tight by plastering the slates, but this only deals with a part of the problem. The important point is the total heat loss from interior to exterior, by air change, conduction, and radiation. Mr. Livock deprecates the importance of heat insulation from the point of view of the electrical engineer, because the advantage is common to all heating systems and the percentage saving is the same. We agree the latter part of the argument but we desire to observe that it is actual cash values that are usually considered to be important, and while a 10 per cent saving on a cheap, low-grade fuel may not amount to a substantial sum, an equal percentage saving on a relatively costly, high-grade fuel may make all the difference between acceptance and rejection of the scheme.

* See pages 1069 and 1070 of Mr. Grierson's 1931 paper (No. 2 in the bibliography on page 506).

Mr. Easton anticipates difficulty in persuading architects to spend money on insulating the structure with a view to reducing the annual cost of fuel and improving the comfort condition during the summer. On the contrary, our experience is that the more enlightened architects are investigating the subject very closely, and frequently invite discussion. We may also mention that the gas engineers are very much alive to the importance of this detail in connection with gas-heated buildings, as is indicated by the space given in the gas journals to the paper by Mr. Westbrook on "The Application of Gas to Central Heating and Bulk Hot Water Supply."*

Mr. Jamieson has taken exception to the figures for heat loss through ceilings, roofs, etc., quoted on page 463. The incorrect conclusion at which he has arrived is apparently due to the loose wording we employed, for the figures are actually based on average and not on maximum winter conditions. The reference to 30 deg. F. was intended to convey the fact that the installation would maintain a difference of 30 deg. F. between the indoor and outdoor temperatures if and when called upon to do so, but that with a mean temperature throughout the heating season of 44° F., and the installation under thermostatic control, the annual consumption for continuous warming would probably be of the order of 1 600 kWh per kW of connected load (as differentiated from maximum demand on the mains, and on the system).

Mr. R. D. Reynolds and several other speakers have requested further information regarding the heat-insulating properties of several of the well-known building boards now on the market, but the normal limits of space have already been greatly exceeded and we must refer them to the classic paper by S. F. Greenland.†

Thermal Capacity of Buildings.

We regret that we failed to make clear to Dr. Faber our intention in writing this paragraph in the paper. The figures given purport to be a mere arithmetical investigation, designed briefly to demonstrate the relationship of the various quantities one to the other, and we do not think we suggest or imply that it could be applied to any particular building, for the very obvious reason that the correction factors would be extremely complicated. The general trend of the discussion indicates that the paragraph has served the purpose for which it was written.

We regret that we are unable to follow Dr. Faber in his argument regarding the "very large margin" required in the heating installation of a normal building, operated on the basis of continuously maintained temperature; and that is the reason why we have ignored the conclusions which we are alleged to have put forward.

The information given by Mr. Grant regarding the ascertained thermal capacity of a 2 million cubic ft. building and the very gradual fall in the temperature after the heat supply has been shut off is most interesting and valuable and should serve to emphasize the importance of this aspect of the subject. With further experience it may be possible materially to reduce the water-storage capacity now considered necessary, thereby reducing the initial cost of thermal-storage installations and rendering them more competitive in the heating market.

Mr. E. A. Reynolds is in error in attributing to Dr. Faber the constant of 0·45 watt per cubic ft., in the tabulated statement on page 464. The article referred to was entirely concerned with structural data, and we are responsible for the application of the data to the heat problem. The value of 0·45 watt per cubic ft. corresponds to a heat loss of 1·53 B.Th.U. per cubic ft., which is a good average value for the buildings of the class and volume mentioned.

The Effect of Various Types of Electric Heating Systems on the Load Factor and on the Distributing Network.

In his discussion of this detail, we can only think that Mr. Cowie has inadvertently confused demand and consumption. Given that the hourly heat loss of a building is 1 million B.Th.U. or 294 kW, then for extreme weather conditions, the possible daily consumption will be 294 × 24 kWh, although it is highly probable that this quantity would not be actually used during the 24 hours. Two alternatives are available to the designer of the thermal-storage plant, i.e. either for the average temperature and total available heat content of the storage water to be assessed at the commencement of the run and the load control automatically to set itself to provide the make-up heat required over the *whole period available*, or for the designer to legislate for the plant to operate at its maximum rated load and to arrange for the automatic devices to switch off the current when the storage has been made up to 100 per cent capacity, whether the period of the run extends to 1 hour or to 12 hours. If the latter course is adopted and if the supply period is 12 hours, the load on the mains will be 294 kW × 24 hours/12 hours, or 588 kW, as compared with the hourly heat loss of 294 kW. The plant may only run for, say, 5 hours to make good the heat loss of the previous day, so that the consumption will be just under 3 000 kWh, the average hourly consumption being at the rate of 125 kWh, as compared with the maximum hourly heat loss of 294 kW and the registered maximum demand on the mains of 588 kW. Again, the efficiency of the system employed must inevitably have a most marked effect on the demand and on the consumption. To take an extreme case, consider a building heated by fixing the electric fires *outside* the building, so that only the radiant heat enters the building through the windows, all the convection heat being lost. As a further step in the investigation, bring the electric fires inside the building and place them in front of the windows so that the high-temperature radiant heat passes through the glass and only the convected heat is employed to warm the building. To extend the investigation, place the high-temperature convectors or radiators under windows where the temperature gradient and the air change have a maximum value, and then compare the consumption for a given period with the condition of comfort maintained and correct this for the weather conditions.

Mr. E. A. Reynolds has questioned the accuracy of the statement on page 466, to the effect that for a building

* *The Gas Salesman*, 1935, vol. 14, No. 186.

† "Practical Determination of Heat Transmission from Buildings," *Journal of the Institution of Heating and Ventilating Engineers*, 1933, vol. 1, p. 507.

having a calculated heat loss of 1 million B.Th.U. per hour, or 300 kWh per hour in round figures (294 kW), the maximum load on the mains will not exceed 60 per cent, or 180 kW. In writing the paragraph, we had in mind that the load would be controlled by thermostats located in the various rooms, and, if the building is divided into offices or other small rooms, experience indicates that the total number of thermostats would be at least 150 and would probably be 200. The heat losses are calculated for the unoccupied, unfurnished, and un-illuminated building, and take no account of the radiant heat of the sun, thermal-storage capacity of the structure, differentials of the thermostat, etc., so that even during spells of severe weather it is not possible to conceive that 100 per cent of the thermostats will be closed simultaneously, just as no supply authority has ever experienced a peak load of 100 per cent of the load connected to its mains. Furniture, merchandise, people, etc., all reduce the gross cube of a building, and hence the total hourly air change and the heat required to warm the air. Casual heat is emitted by the occupants; modern lighting equipment is introduced into the building; heat losses through walls are restricted by curtains, wall paper, panelling, merchandise, filing cabinets, pictures, etc.; the wind blows from only one direction at any given time; the sky is cloudy and restricts radiation to space; the sun shines on one side of the building; a thermostat cuts off $1\frac{1}{2}$ deg. F. above the predetermined temperature and there is an interval of several hours before it reaches the lower differential or switching-in point. All these items produce diversity between the connected and the actual maximum load registered at the consumers' terminals. Proof of the existence of this diversity is given in Fig. 9 of the paper, and in Figs. 15 and 17 of the 1931 paper on "The Electric Heating of Buildings."

During the cold spell that occurred on the 9th, 10th, and 11th March, 1935, an installation having a connected load of 120 kW only used 740 kWh during the period of 24 hours, instead of its rated maximum figure of 120×24 or 2 880 kWh, but it is probable that several sections of the building used the maximum possible number of units, while others used considerably less.

Several speakers have interpreted Fig. 1 in a manner that was not intended by us. The load graph was included as being typical of a modern, well-developed, provincial system supplying a load of a diverse character, i.e. works, domestic, rural, etc., and it was not intended to show and does not show—so far as we are aware—any special development of the electric fire, thermostatically-controlled unrestricted hour, or thermal-storage type of heating load.

The increase in the value of the loading from 573 kW to 1 430 kW, shown in line "e" on page 464 and queried by Mr. Low, is due to the operation of the efficiency and time factor. For a heat requirement of 573 kW and 80 per cent distribution efficiency (heat lost from the electrode heater, storage vessel, circulating pumps, and pipework, and not efficiently utilized to maintain the desired temperature in the occupied parts of the building) the input to the heater must be increased to $573 \times 100/80$ or 715 kW. Again, if the heat load of 715 kW is to be supplied for 24 hours per day and the supply is only available for 12 hours daily, then the input to the heater must necessarily be $715 \times 24/12$, or a total of 1 430 kW.

In further reply to Mr. Low, it is extremely difficult to give any general indication of the position of the boundary line that determines whether a building should be equipped with a direct or a thermal-storage plant, as there are so many factors that will affect the decision. Certainly it is not the heating cube of the building, for we have installed an 18 kW thermal-storage plant in one building and 180 kW of direct heating-surface of the "wired fabric" type in another building. Space for plant, tariffs, and the cost of labour, are probably the most important factors.

Annual Consumption of Fuel, Gas, and Electricity.

The graphs reproduced in Figs. 3, 4, and 5, were compiled for the purpose of reducing the calculations of annual consumption to a definite mathematical process which, by the judicious selection of appropriate constants, would rapidly yield reasonably consistent results. They were not compiled for the purpose of comparing the costs of electricity, oil, and coke, as suggested by Dr. Faber, although they can, of course, be used for that purpose. The efficiency values, to which Dr. Faber takes exception, are merely reprinted from the paper by Mr. Barker,* and, again, appropriate values must be selected for the installation under consideration.

The data contributed by Mr. Cowie form a valuable contribution to the discussion, and we trust that it will be possible for the figures to be analysed and included in the statistical data which, we understand, is now being collected by the British Electrical Development Association.

The information given by Mr. Engholm is insufficient to enable us to make any estimates of annual consumption that would serve any useful purpose and that would not be liable to incorrect interpretation. We think that he should experience no serious difficulty in obtaining the desired data from Figs. 3, 4, and 5.

Mr. Parker desires information on the highly contentious subject of the operating costs involved under the continuous and intermittent methods of warming buildings. Conditions vary so greatly that it is difficult to give any general reply. Certainly, for the larger, fully-occupied office, flat, and hotel, tests show that the maintenance of the temperature throughout the heating season uses no more fuel or energy than by the intermittent method, and that the comfort condition is vastly superior. Further, it would appear to be a more logical proceedure to utilize the cheap units that are available during the night for this purpose, than to switch off the installation during the period when units are cheap and then to impose on the mains excessively heavy loads that will coincide with the breakfast and power peaks. For the corrugated iron or thin asbestos-sheet building provided with a large area of glazed north light, and a very frequent air interchange due to poor design or construction, the thermal capacity of the structure is extremely low, and if the period of occupation is from 35 to 40 hours per week it is obvious that no material advantage is to be gained by endeavouring to maintain the temperature.

* See Bibliography.

The distribution of the demand for heat on central-heating systems throughout the heating season is shown in Table B.

We had not intended that Fig. 2 should be used to obtain the annual consumption in the manner suggested by Mr. Gregory, for the reason mentioned in our reply above to Mr. Cowie. The graphs in Figs. 3, 4, and 5, were prepared for this purpose.

Tariffs.

We are pleased to learn from Mr. Cowie that supplies at rates of the order of 1 200 and 1 400 units per £ have been in operation for a number of years, but it will be interesting to learn what effect the C.E.B. tariff will have on those agreements when they fall due for renewal.

Mr. Shand, Mr. Cooper, and several other speakers, have supported the view we expressed regarding the necessity for the development of the fixed-annual-charge type of contract if it is desired to develop the heating and hot-water supply load; further experience of the activities of representatives of the gas, coal, and coke industries confirms this view.

Although we cannot but feel inclined to agree with Mr. D. J. Bolton when he suggests that we have overstated the consumption of hot water in the average suburban residence, we think that he has erred on the high side in putting the average secondary rate for hot-water supply as low as 320–480 units per £. Before water-heating becomes really popular, the rate must be of the order of 700–800 units per £. Rates of 650 units per £ are now fairly common for an unrestricted supply, owing to the very diverse nature of the load and to the fact that the hot-water peak seldom coincides with other serious peaks. In fact, we doubt whether any supply authority experiences any serious demands due to the use of hot water between the hours of 3 and 7 p.m.

We regret that we cannot endorse the proposals of Mr. Cunnington to utilize a hot-water boiler for supplying the base heating-load and to employ electrical energy exclusively to deal with the excessively cold periods. The load factor of such an installation would probably be less than 5 per cent, and the cost of units to the supplier, under the grid tariff, would be at the rate of 100–150 units per £. Allowing for the usual on-costs, the rate to the consumer would be of the order of 50–60 units per £ and the cost would be prohibitive, even if he could persuade any undertaker to supply him.

The further tariff suggested by Mr. Swale appears to be a retrograde step, because the average of the 300 and 600 units per £ quoted is of the order of 400 units per £, and, as Mr. Cowie has stated, very much better rates have been available for some time.

By way of contrast to the support given by Mr. Shand and Mr. Cooper to the fixed-annual-charge type of contract, Mr. Fennell and several other speakers have expressed varying degrees of alarm at the mere suggestion. Is not every contract for constructional work, and indeed for practically all classes of work, based on the counterpart of the "grid tariff," for have we not the fixed charges of the "overheads," the material, and the labour? Yet contractors necessarily make more or less accurate estimates as to the probability of the costs and fix their selling price accordingly. Again, is not all insurance work carried out on the basis of probability of accidents, fires, and the like, and is not the premium quoted accordingly? If the premium is based on the probability of all the buildings, cars, lives, etc., becoming a total loss, in the same year, then no business would be done; but reserves can be built up to equalize the lean with the profitable years.

Mr. Dean appears to have fallen into the common error of confusing the connected load of the installation and the maximum demand at the consumer's terminals; also of assuming that such maximum demand will coincide with the system or district peak. Our experience is to the effect that 60 per cent of the connected load represents the installation demand, and that 1 600–2 000 units per kW of installed load is a more usual figure for a well-designed, continuously operated, thermostatically controlled, direct electrical heating installation. Therefore, instead of a consumption of 1 000 units per kW of maximum demand, we suggest the value is nearer

TABLE B.

Monthly and Quarterly Heat Requirements expressed as Percentages of the Annual Consumption.

Month	Mean temperature for month, °F.	Temperature-rise to maintain 63° F. mean	Per cent of total power used, i.e. of 35 deg. F. rise provided	Monthly consumption as percentage of annual consumption	Quarterly consumption as percentage of annual consumption
October	51·2	11·8	35·7	9·2	
November	45·0	18·0	54·5	13·5	39·5
December	41·3	21·7	65·8	16·8	
January	39·6	23·4	70·8	18·2	
February	40·7	22·3	67·5	15·7	49·3
March	43·1	19·9	60·3	15·4	
April	48·2	14·8	48·8	11·2	11·2
Totals	44·1	18·8	—	100·0	100·0

2 000 units on a demand of 0·6 kW, so that the annual load factor of the installation is in excess of 30 per cent and the corresponding grid price to the undertaker, assuming no diversity factor between the installation peak and the system peak, would be of the order of 510 units per £.

The figures of 500 and 1 000 units per £, queried by Mr. Seddon, are for the actual cost to the consumer, if the heat developed by these units is to be on a competitive basis with coal and coke. We definitely feel that if electric fire loads are supplied over the peak period and during exceptionally severe winters at rates of 320 units per £, then the thermostatically-controlled heating load, used night and day, throughout mild and severe winters is definitely entitled to a substantially lower rate.

Mr. Higham has contributed interesting operating data relating to his own residence, the total annual cost being approximately £20. One of the authors has the good fortune to reside in the Watford area of supply, where the total annual cost of 11 000 units per annum amounts to the same figure of £20, which corresponds to an average rate for all purposes (including lighting, heating, cooking, and hot-water supply) of 550 units per £.

Mr. Corson has raised the interesting point regarding the possibility of a fixed-price annual contract being held to be a contravention of the "undue preference" or "similar circumstances" clause of the 1886 Act. If there is any doubt about the matter, we anticipate that our friends in the gas industry will lose no time in raising it in a well-known London area of supply where they find the competition particularly keen.

In closing our reply to this section of the discussion, may we draw attention to the fact that, in his speech to the shareholders of the County of London Electric Supply Co., Sir Bernard E. Greenwell mentioned the fact that for the six weeks prior to the meeting held on the 19th March, 1935, the thermal efficiency of the new plant at Barking had never fallen below 28½ per cent, and that for the year 1934 the cost of coal per unit sent out for the whole station was 0·098d., or at the rate of 2 450 units per £.

Again, according to Appendix 1 of the paper by Mr. Westlake,* in the year 1941 the Board for Northern Ireland anticipates that it will sell 55 million and purchase 63·5 million units, so that the efficiency of distribution and transformation is presumably anticipated to be 86·6 per cent over an area of practically 3 000 square miles, having a population density varying between 250 and 90 per square mile.

If this figure of transformation and distribution efficiency for Northern Ireland is applied to the Barking coal costs, the actual coal costs at the consumers' terminals would amount to 0·116d. per unit, which is equivalent to a rate of 2 060 units per £ for an off-peak load. We merely quote these figures in reply to several speakers who have suggested that we have taken a too optimistic view regarding the cost of electrical energy for off-peak supplies in the near future.

Direct Electric Heating.

In regard to dusting or pattern staining of the "Dulrae" or wired-paper ceiling-heating system; referred to by Mr. Seddon, this difficulty has been largely overcome by restricting the use of the system to flat ceilings so that convection is at a minimum value; also by applying one of the well-known building boards (based on plaster of paris) to the lower surface of the warming fabric, and by paying special attention to the heat insulation of the ceiling. This has the effect of smoothing out the temperature gradient and, hence, the local air circulation, so that in districts where the air is reasonably clean the intervals between re-decoration can be extended to periods of two years or longer.

Mr. R. D. Reynolds has expressed regret that we did not deal at greater length with high-temperature panels controlled by radiant thermostats; although we regret the omission, the restriction on time and space was predominant and there is little new development to report since the 1931 paper by Mr. Grierson. The claim that the tubular heater is essentially a radiator and not a convector was discussed, and was illustrated in Fig. 1 of that paper, where it was shown that the arc of exposure to the room, when fixed on the skirting board, could not exceed 60°; this corresponds to 16·6 per cent of the total surface of the tube. It is not possible to assume that the heat from this arc of exposure is wholly transmitted by radiation, so that the radiant efficiency would appear to be of the order of 10 per cent. A higher radiation value should be obtained from the oval tube.

Thermal Storage.

Mr. Hooper has suggested that manufacturers should concentrate on the sale of self-contained thermal-storage units. As this is a novel proposition, we have briefly investigated the relevant technical data. Assuming an average suburban house of the more popular type having a floor area of 800 ft. super, and two floors averaging 9 ft. in height, the heating cube will be 14 400 ft., or, in round figures, 15 000 ft. Assuming the use of reasonable heat insulation, and a heat loss of, say, 2 B.Th.U. per cubic ft., the total heat loss would be 30 000 B.Th.U. per hour, which is practically equivalent to a loading of 9 kW, and if the supply can be given for 16 hours per day, the heater capacity would be $9 \times 24 \div 16$, i.e. 13½ kW. In regard to storage capacity, assuming a horizontal cylinder located on the ground floor and an expansion tank in the loft space, it should be possible to provide a static head of 15 ft., which corresponds to a boiling point of 231° F., and this could be increased to 250° F. by the introduction of a column of mercury into the expansion pipe. Assuming the maximum working temperature to be 230° F. and the minimum flow temperature to be 140° F., then the temperature range would be 90° F. (allowing a margin of 20 deg. F. between the boiling point and the maximum safe working temperature), and each gallon of storage water will be capable of yielding up 900 B.Th.U. during the discharge period. As the total heat required is 30 000 B.Th.U. per hour and the storage period is 8 hours, the total net storage capacity required is 240 000 B.Th.U./900, i.e. 2 666 lb. of water. Adding 10 per cent for expansion water, etc., the storage capacity required is 292 gallons, a convenient size of vessel being 3 ft. 6 in. × 5 ft. At 400 volts, the phase current corresponding to 13·5 kW is 19·5 amperes, and a 25-ampere triple-pole contactor would be required.

* C. R. Westlake: "Electrical Development of Northern Ireland." Paper read before the I.E.E. Transmission Section, 23rd January, 1935.

The probable annual consumption would be between 18 000 and 20 000 units, which if priced at 1 000 units per £ would amount to £20 for the off-peak supply. If a basic temperature of 55° F. is maintained by the thermal-storage system, and electric fires are used as local "boosters," as and when required, the consumption on the thermal-storage system would be proportionally lower.

Mr. Rawll has drawn the conclusion from an inspection of Figs. 20, 22, and 23, that the vertical storage vessel is more efficient than the horizontal type, but we would emphasize the fact that the curious shape of the graphs in Fig. 22 is not inevitable in the latter type. The graph was merely inserted as being of special interest.

We feel sure that Mr. Waygood will appreciate, on reflection, the fact that his direct question relating to the space occupied by thermal-storage plant does not admit of the simple answer that he appears to contemplate, and we must decline, without the conditions being more fully defined, his ingenuous invitation to commit ourselves to a positive statement.

Immersion Heaters.

The reasons given by Mr. Low for his preference for the semi-enclosed type of insulator or former are very interesting and authoritative, in view of his extensive experience with this class of apparatus. We anticipate that standardization will proceed along these lines, and if anything can be done safely to increase the loading per inch of length it will be a great advantage, for difficulty is frequently experienced in providing space for vessels having a diameter suitable for long heaters.

The heater described by Mr. Livock is definitely an endeavour to overcome certain practical difficulties, but the essential factor of replacement without emptying the water appears to have been disregarded.

Several speakers having requested information as to the life of immersion heaters, we would reply that in our experience it is an unusual event to receive a complaint regarding the failure of a modern type of low-loaded heater tube or element, because the experienced manufacturers have eliminated the majority of the weak points that appeared in the earlier designs. In regard to protection from corrosion, tinning appears to be the best solution to date, but here again we have little or no experience of element failure due to contact with rust forming within the tube. Copper tubes should certainly be used, in conjunction with gun-metal face plates, on soft-water supplies. We prefer the method of expanding steel tubes into face plates of boiler plate, because we see no definite advantage in the threaded joint, and the latter is of questionable utility, for it is difficult to remove a single tube from a bank of heaters without the use of a special box-type spanner and without entirely dismantling the whole group.

In view of the evidence advanced by Mr. Fletcher regarding the improved design of the blade type of heater, and of the satisfactory operating experience that he mentions, we were possibly unduly severe in the paper in our remarks relating to this type, although, as an engineering proposition, we feel that we must still express a preference for a straight steel tube expanded into a substantial piece of boiler plate.

In reply to Mr. Bolton, we have never used asbestos in association with nickel-chrome wire, as the former is notoriously hygroscopic and therefore a partial conductor. In the personal experience of one of us, a man received a severe shock which caused him to fall off a pair of high steps. Investigation showed that the man's mate had removed the fuse wire from the carrier, left the asbestos stocking in place, and replaced the fuse carrier in its contacts, with the result that the hygroscopic asbestos stocking passed the few milliamperes required to administer the shock to the workman.

Electrode Heaters.

In reply to Mr. Mallinson, we have no knowledge of any insurance company requiring the valve to be fitted with padlocks on either the flow or the return pipe of the electrode heaters, but we have equipped several of the most recent installations with a "flow" contact on the circulating pipe, arranged in a manner such that the main contactor can only close and remain closed when water is actually flowing through the heater.

We are unable to follow the argument developed by Mr. Swale in regard to the time/current graph of electrode heaters, because Fig. 14 (A) to which he refers is a steam boiler and holds a very small quantity of water, and the conductivity of the feed water can be readily adjusted. Fig. 15 (B) illustrates the water-heating counterpart of Fig. 14 (A) and, by the adjustment of the conductivity of the water and the operation of the load controls, full load can be obtained within 30 minutes of closing the control switch, the insulated load-control shields automatically descending to cover the electrodes and so restrict the flow of current to the predetermined value as the temperature and conductivity of the water rise.

In further reply to Mr. Swale, experience shows that the possibilities of trouble from the earth leakage current from electrode heaters has been unduly emphasized, and it is thought that with the ever-increasing adoption of the multiple-earthed neutral system of a.c. distribution, the installation of this type of apparatus will be an advantage to the distributing network. We would also direct the attention of Mr. Swale to the remarks of Dr. Garrard on this point, and to the I.E.E. Regulations for the Electrical Equipment of Buildings, which latter call for the installation of unbalanced-phase protective gear.

Dr. Garrard comments on the loss of heat that occurs when hot water is expelled from a steam boiler following the sudden cessation of load; but this should not be serious if it is expelled into an efficiently lagged hot-well.

In the Birmingham discussion, Mr. Cox expressed a preference for rating the electrode heater on the maximum continuous output—presumably at the maximum operating temperature—but we still feel that the rating should be based on the average output during the heating period available, this being less liable to cause confusion.

Regarding the restrictions relating to the connection of 400-volt electrode heaters to the distribution system, we would refer Mr. Jamieson to paragraph 4 of the Electricity Supply Regulations, 1934, in which it is laid down that "The connection with earth shall be made

at one point only in each distinct system, unless connection with earth at more than one point is for the time being approved by the Electricity Commissioners with the concurrence of the Postmaster-General and is made . . ." Probably Mr. Jamieson was thinking of par. 30(*b*) when he stated that the restriction referred only to high-voltage heaters.

Mr. Clark has invited us to discuss the relative merits of the adjustable water-level as against the adjustable shield method of controlling the load of electrode steam-boilers, but we regret that restrictions of space do not permit of this.

Mr. McQueen suggests that the electrodes should be inserted through the base of the heater and refers to the limited amount of sludging or scaling that should occur on a closed system of radiator or panel heating. Whilst it is true that little raw water should be introduced into the system during a period of years, yet scale, sludge, and magnetic oxide, do accumulate in the heaters and storage vessels connected to an extensive system of pipework, radiators, etc., and adequate sludge space and facilities for its easy removal are certainly a desirable feature of any heater.

Mr. Marden has invited us to express our personal preference in regard to the design of the heaters, but in view of recent developments and improvements in design it would be inadvisable to make any distinction at the present juncture. We have already dealt at some length with the water problem, but, in further reply to the same speaker, where the resistance of the water is too low for satisfactory operation and it has not responded to heat treatment to the required degree, it may be necessary to modify the construction of the heater, or to introduce soft water from the nearest convenient source of supply, or to install an evaporating plant.

In reply to Mr. Swift's inquiry regarding the possible advantages of lowering the pressure to 100 volts where the supply is obtained from a local transformer, we do not consider that this would be practicable, for the reasons that the necessity for isolation from the mains has been proved to be unnecessary, that the cost of the special transformer would unduly load the cost of the installation, that there would be considerable difficulty in handling the heavy currents necessary at these low pressures, and that the amount of copper involved would be excessively costly.

A certain amount of misconception undoubtedly exists in the minds of many electrical engineers to-day, when they are more concerned with the characteristics of transformer oil than with feed water, regarding the kindred subjects of the hardness of water, precipitation, and conductivity. A few lines may therefore profitably be devoted to the consideration of one or two fundamental facts associated with water and its treatment when used in electrode heaters and boilers.

Pure water is practically an insulator, and, generally speaking, the presence of impurities reduces the resistance and increases the hardness. To answer the question "How does water vary in different parts of the country?" we have extracted the following analyses from J. H. Paul's "Boiler Chemistry and Feed Water Supplies."

The unit of "grains per gallon" does not convey any very definite idea to the engineer who is dealing in units of pounds (weight) and thousands of gallons, but the unit conversion is a very simple one, for it is only necessary to multiply by 1 000 and divide by 7 000, or, briefly, to divide by 7 in order to convert grains per gallon into lb. per 1 000 gallons. For example, in Table C, the amount of impurities in London water per 1 000 gallons is 26·86/7, i.e. 3·83 lb. Again, if the information is issued in the form of "parts per 100 000," which is the method adopted by the Metropolitan Water Board, the conversion to "lb. per 1 000 gallons" is effected merely by moving the decimal point one place to the left, e.g. 24·2 parts of $CaCO_3$ in 100 000 parts of water becomes 2·42 lb. per 1 000 gallons.

To answer the questions "Which of, where, and when will these impurities be precipitated?" one has to throw one's memory back to one's student days and recall the fact that when water is heated without boiling, gases are driven off and certain of the impurities become insoluble. The carbonates of lime ($CaCO_3$) and magnesium ($MgCO_3$) are held in solution by the free carbonic-acid gas (CO_2), which converts them into the bicarbonates $CaH_2(CO_3)_2$ and $MgH_2(CO_3)_2$, and when this is driven off by the process of heating, the two substances mentioned become insoluble, are precipitated in the form of the carbonates previously mentioned and are therefore classified as "temporary hardness." In order to increase the conductivity of the water we stated, on page 476 of the paper, that "soda" or washing soda (Na_2CO_3, $10H_2O$) was commonly used, and this compound is largely employed in many commercial water-softening processes for the precipitation and removal of calcium chloride ($CaCl_2$), calcium sulphate ($CaSO_4$), calcium nitrate [$Ca(NO_3)_2$], magnesium sulphate ($MgSO_4$), and magnesium chloride ($MgCl_2$). all of which are classified as "permanent hardness." The chloride, nitrate, and sulphate, of sodium usually remain in solution.

As the hottest part of the water system is the electrode heater, one naturally expects that most of the precipitation will occur there, the heavier substances remaining and the lighter passing along in the stream of water to other parts of the system. According to Paul, only a part of the carbonate of lime forms scale, the remainder being precipitated as sludge; and Collett* states that the presence of carbonate of soda also aids and quickens the precipitation of the carbonates of lime and magnesia and has the curious effect of causing these carbonates to be precipitated in a smaller, finer, and lighter condition than if heat alone were used. The same author also states that carbonate of soda does nothing to diminish, but frequently increases, precipitation, and he instances sulphate of magnesia, which, in the absence of carbonate of soda would remain soluble, neutral, and harmless. Sulphate of lime is crystalline, settles down quickly and makes hard scale.

In regard to the total quantity of water available, and the velocity of the water through the heater, a typical installation had a storage vessel of 6 000 gallons, was filled with water containing $3\frac{1}{4}$ lb. of the sulphate and carbonate of calcium and the chloride and carbonate of magnesium per 1 000 gallons, or a total of $19\frac{1}{2}$ lb., which, at 60 lb. per cubic ft., would occupy approximately

* H. COLLETT: "Water Softening and Purification."

$\frac{1}{3}$ cubic ft. The capacity of the heater was approximately 100 gallons, and although the velocity of the water in the pipes would be of the order of 4 ft. per sec., the velocity through the heater would probably not exceed 0·75 in. per sec.

The other probable sources of impurity are the hammer scale or "magnetic oxide" which is formed on the surface of the pipes and the plates of the storage vessels during the process of manufacture and consists of the black ferroso-ferric oxide of iron (Fe_3O_4 with more or less ferric oxide Fe_2O_3), and also silicon dioxide (SiO_2), that both iron and silica are present in all of the five waters mentioned.

Another effect of the introduction of soda into the water is that it may attack asbestos jointing rings and quartz insulators; but the soda can be brought practically to the neutral point by the addition of oxalic acid ($C_2H_4O_5$), which has the merit also of lowering the resistance of the water. It is, of course, a poisonous substance and therefore requires care in use, the water being left slightly alkaline so that there is no possibility of its developing an acid characteristic.

TABLE C.

Typical Analyses of Various Waters.

(*Compiled from "Boiler Chemistry and Feed Water Supplies," by J. H. Paul.*)

Constituent	Formula	Precipitated or removed by	Grains per gallon					
			Glasgow (soft)	Liverpool (soft)	Brighton (chalk)	London (hard)*	Coventry (hard)	Hartlepool (very hard)
Calcium carbonate ..	$CaCO_3$	Heating	—	0·27	14·31	12·39	11·90	20·55
Calcium chloride ..	$CaCl_2$	Soda	0·08	—	—	—	—	—
Calcium nitrate ..	$Ca(NO_3)_2$	Soda	—	—	—	0·56	—	—
Calcium sulphate ..	$CaSO_4$	Soda	0·51	2·21	—	6·37	2·50	4·39
Magnesium carbonate	$MgCO_3$	Heating	—	—	0·55	—	—	—
Magnesium chloride	$MgCl_2$	Soda	0·19	0·98	—	—	—	—
Magnesium nitrate ..	$Mg(NO_3)_2$	—	—	—	—	—	—	—
Magnesium sulphate	$MgSO_4$	Soda	—	0·21	—	1·54	6·12	18·49
Sodium carbonate ..	Na_2CO_3	Lime and calcium sulphate	—	—	—	—	—	—
Sodium chloride ..	NaCl	Distillation	0·51	0·84	4·10	3·27	2·45	18·02
Sodium nitrate ..	$NaNO_3$	Distillation	—	—	2·97	2·38	2·09	1·12
Sodium sulphate ..	Na_2SO_4	Distillation	—	—	0·64	—	—	—
Iron oxides	Fe_2O_3	Soda and filtration	0·03	0·10	0·10	0·14	0·11	0·17
Silica	SiO_2	—	0·06	0·17	0·17	0·21	0·19	0·22
Total grains per gall.	—	—	1·38	4·78	22·84	26·86	25·36	62·96
Hardness (degrees) ..	—	—	0·65	3·10	14·95	18·7	18·85	39·18

NOTES.

* See also page 547.

(*a*) It is regretted that corresponding figures are not available for resistance, but it may be of interest to note that at a temperature of 96° C. the soft Birmingham water gave a value of 4 500 ohms, and Coventry water 726 ohms per cm cube.

(*b*) An 8 000-gallon 400-volt installation at Liverpool required 36 lb. of soda and 9 lb. of oxalic acid to lower the resistance of the water to the desired value.

which may remain in the sectional cast-iron radiators in the form of sand from the cores employed in the foundry to form the water ways of the radiator. The sand may be either washed out of the radiators or it may be dissolved by the hot water containing the washing soda (added for increasing the conductivity) when the silicate of soda [$Si(NaO)_4$] may be produced, but this may be further converted in the presence of lime or magnesia. The mere presence of silica or iron in the analysis of the substance removed from the heater does not necessarily prove that the hammer scale, the wasting of the electrodes, or the core sand, are the source of the impurities, as reference to the table of water analysis will indicate

In order to limit the increase in the scale and sludge precipitated by the use of soda, one manufacturer recommends the employment of bicarbonate of soda ($HNaCO_3$) for lowering the resistance of the water, but when the solution is heated carbonic-acid gas should be released and the salt should be converted into the normal carbonate (Na_2CO_3, $10H_2O + CO_2$). Paul inadvertently subscribes to this bicarbonate theory when he mentions, in discussing the softening process, that the nitrates of lime and magnesia, the sulphate of magnesia, and the chlorides of calcium and magnesia, are decomposed after the free carbonic acid has been eliminated. If it has not been removed, a portion of the soda is con-

verted into the bicarbonate of soda, and as this does not precipitate completely any of the above materials so much of the soda is wasted. Collett also mentions that the bicarbonate of soda is never used for water softening, as it would need to be caustified with lime to be of any use, i.e. it is comparatively inactive in causing precipitation. The objection raised to its use is that it is said to introduce still more carbonic acid into the system, but the manufacturers contend that, for various reasons, it is practically innocuous.

The following is a typical example of scale taken after working through two seasons from a pair of 300-kW 400-volt electrode heaters supplying a radiator system, filled from the Metropolitan Water Board's mains, and treated with soda for the reduction of electrical resistance.

	per cent
Calcium carbonate	90·25
Magnesium carbonate ..	3·46
Iron as FeO	3·60
Manganese as MnO	0·06
Siliceous matter	1·04
Organic matter	0·86
Moisture	0·46
Other matter	0·27
Total	100·00

An obvious method of eliminating the calcium carbonate in this scale would be to fill the system with water softened down to about 4 degrees.

In one London building equipped with high-voltage electrode heaters, the water supply was originally obtained from the Metropolitan Water Board, but a well was sunk and the original supply was disconnected. Difficulty was then experienced, owing to the excessively low resistance of the new water, and we therefore reproduce in Table D an analysis of London waters quoted by Mr. A. C. Pallot (see Bibliography).

On the change-over to the well water, the carbonates of calcium and magnesium would be precipitated by the release of the carbonic acid on heating, and would leave the carbonate, sulphate and chloride of sodium which are all difficult to eliminate and are frequently used to improve the conductivity. Distillation alone is effective for the removal of the sodium chloride.

TABLE D.

Analysis of Typical London Waters.

Impurity	Metropolitan Water Board			Artesian wells		
	Grains per gallon			Grains per gallon		
	1	2	3	1	2	3
Calcium carbonate	10·77	11·77	17·30	4·02	2·70	3·4
Calcium sulphate	3·14	2·42	4·40	—	—	—
Magnesium carbonate ..	0·73	0·95	0·53	1·59	1·47	0·7
Magnesium chloride	0·20	—	0·62	—	—	—
Sodium carbonate	—	—	—	11·9	14·56	15·5
Sodium chloride	2·18	2·46	2·34	12·0	16·17	16·5
Sodium sulphate	—	1·35	—	12·4	15·68	18·4
Silicon dioxide	0·29	0·26	0·98	} 1·53	1·67	0·9
Other	0·09	0·11	—			
Totals	17·40	19·32	26·17	43·44	52·25	55·4

Time and Temperature Control of the Load.

In reply to Mr. Fielding, our experience of thermostats has been restricted almost entirely to the straight bimetal strip with air-break contacts, the gas-filled bellows, or the capillary tube operating a mercury switch. With very few exceptions, these types have given satisfactory results and the differentials are usually within $\pm 1\frac{1}{2}$ degrees F. for the standard commercial instruments, although differentials of a fraction of a degree can be obtained when this is essential. The differential does not appear to increase with age, although, in a few instances, the operating point has been found not to agree with the calibrated scale. In fact, we consider that the makers are to be congratulated on the production of an extremely useful instrument that is so reliable and reasonably accurate at such a low price.

Mr. Price would like our observations on the application of the superimposed harmonic system of selective load control to a 30 000-kW system, but we must refer him to the manufacturers for details as we have no

practical experience of the operation of the equipment.* We understand, however, that it is in very successful operation on the distribution system of Paris, where it is employed to control the 3-rate meters, switching over the dials at predetermined hours each day.

Mr. Pickard refers to the possibility of a temperature-predicting instrument, so that prior to a fall of temperature heat may be pumped into the building. He mentions an instrument of the mast type, projecting 100 ft. into the air; but would it not be possible to design a compact instrument operating on the temperature differential between successive readings made at intervals of, say, 1 hour? A gradual change would call for no special activity on the part of the plant, but a steep slope would necessitate a material alteration in the setting of the control system.

Control and Protection of Electrical Circuits and Apparatus.

We think it will be agreed that it is curious that so few speakers discussed this section of the paper. We agree with Mr. Grant when he expresses the opinion that control gear is becoming too complicated. It will be recalled that in the paper we made a very definite plea for simplicity, in order that the cost of the plant should compare not too unfavourably with the competing sectional cast-iron and mild-steel heating units. Mr. Grant, in mentioning that thermal-storage plant is achieving a reputation for unreliability, must, we think, have been referring to one or two of the earlier installations, as, in our experience, once the preliminary adjustments have been effected on modern plant, a brief periodical inspection and an annual overhaul are all that are found to be necessary.

The information given by Mr. Cowie and Mr. Leyburn in regard to fault protection is most valuable, and we hope that it will be possible for one of these two speakers to deal with the subject at greater length at an early date.

Insulation of Thermal-Storage Vessels and Pipes.

Dr. Griffiths suggested that the information given on this subject should be amplified, but we must plead that the paper is a general one, dealing with very many details of this "polyphase" subject, and must of necessity be more in the nature of a review than a complete treatise on any component part. We would therefore suggest that members desiring further information on this subject should consult the standard works, including the paper by Dr. Griffiths.†

In reply to Mr. Mallinson the information from which the graph in Fig. 24 was prepared was, as stated in the paper, supplied by the various manufacturers and we experienced some difficulty in co-ordinating the data obtained by various observers. Again, the data employed in preparing Table 19 were obtained from recognized authorities, have been in daily use in the heating industry probably for the last 50 years, and have given reasonably satisfactory results. All these data clearly require confirmation or correction now that electrical methods are available which enable the amount of heat supplied and also the heat losses, temperatures, etc., to be accurately measured.

Mr. W. Wilson has inquired our reason for excluding cow-hair felt from the materials referred to in Fig. 24, but we would direct his attention to the desirable qualities of heat-insulating materials scheduled on page 490, and particularly to items (*e*), (*g*), and (*i*), for which we are of the opinion that it would receive a low assessment.

Domestic Hot-Water Supply.

Our remarks regarding the daily consumption of hot water have raised an interesting discussion, and, on balance, the views of the various speakers appear approximately to cancel out, although we agree that for the average suburban house we have probably overstated the consumption. Conversely, actual figures obtained from the larger blocks of luxury flats indicate that still higher consumptions must be provided for. Mr. Bolton's remarks are dealt with under "Tariffs."

Mr. Reynolds has directed attention to the fact that there is a discrepancy in the heat losses given in the Tables 17 and 18, but this is only to be anticipated when it is realized that there is no standard lagging or shape of heater. The actual value of the heat losses for any given heater must necessarily be obtained from the makers, information being given regarding the mean temperature difference between the water and the air of the room in which the heater will be located.

We have no experience of the vertical type of heater which is inserted in the top of the vessel, as mentioned by Mr. Rawll, and we therefore regret that we do not feel qualified to express an opinion regarding the merits of the arrangement. Stratification of the hot and cold water and the direction of the convection currents are vital factors in selecting the location of the thermostat.

Cooling by the Invisible Ceiling-Panel System.

In reply to the inquiry by Dr. Griffiths, regarding the precautions taken to prevent the condensation of moisture on ceiling-panel surfaces cooled during the summer, this is effected by automatic temperature control of the cooled water flowing to the panels, the temperature-control apparatus being itself controlled by the dew point prevailing in typical rooms in the building. In principle, the system operates as a reversed thermal-storage system with electrode heater, the details of which are shown in Fig. 16.

Air Conditioning.

Our thanks are due to Mr. Pallot for his description of the unique method employed by Mr. Macintyre to stabilize the humidity conditions in the Lower Orangery at Hampton Court Palace. The points that immediately occur to us are the risk of cultivation of insect and vegetable growth in warm and more or less damp textile material, and the methods employed to render it sterile. Unfortunately, no information was given regarding the precaution taken and experience gained in this direction.

The Heat Pump.

This subject, strictly speaking, is not within the scope of the paper, since the paper purports to be a critical examination of present practice. Nevertheless, we

* See also page 1081 of Mr. Grierson's 1931 paper (No. 2 in the Bibliography on page 506).

† "Thermal Insulation," *Journal of the Royal Society of Arts*, 1933, vol. 81, pp. 911, 930, 945.

welcome the very valuable contributions by Mr. Haldane and several other speakers, but it is obvious that much water must flow under London Bridge before the heat pump can be seriously regarded as a rival to the immersion and electrode heater plant for the warming of large buildings. The application to the warming of swimming baths appears to be a more attractive proposition where the water capacity may be anything between 50 000 and 600 000 gallons; and it is probable that development will proceed in that direction, as the costs should not be loaded with the kW charge if the energy is used exclusively during the summer season. Even in the winter the supply period may be restricted, as the temperature-drop of 100 000 gallons over several hours is negligible.

A brief examination in connection with a new municipal building to be erected in London indicates that, if it is necessary to use the surrounding atmosphere as the source of low-grade heat, the savings that can be effected in demand and consumption are approximately 60 per cent as compared with a standard electrode or immersion-heater plant operated continuously, i.e. a 400-kW plant of the heat-pump type would do the work of a 1 000-kW electrode or immersion heater. Since the temperature range is necessarily low, thermal storage of the normal type does not appear possible, and it therefore seems necessary to contemplate the continuous operation of the plant throughout the peak period of 6 hours, so that it would incur the kW charge; and the cost of 400 kW at even £5 per kW would purchase 2 million units if taken off-peak at the rate of 1 000 units per £. For the building in question, a 240-b.h.p. motor-driven ammonia compressor of the reciprocating type would be required, together with a 20-b.h.p. fan designed to deliver 70 000 cubic ft. of air per minute, and an air cooler containing 25 000 ft. or $4\frac{1}{2}$ miles of $1\frac{1}{2}$-in. copper pipe (possibly in duplicate to allow periods for de-frosting). To make this plant entirely automatic and perfectly reliable so that it could be left entirely unattended over periods of days and weeks would require careful thought and design, whereas electrode and immersion-heater plants are daily being sold on this basis, the control being entirely by means of clock-operated switches and thermostats. This is the position as we see it at the moment, but we are closely investigating the problem with a view to installing this type of plant if and when a suitable opportunity arises.

Conclusion.

In conclusion, may we once again say how much we appreciate the discussion that the paper has produced. We think that it will be generally agreed that it has served a useful purpose in causing the various aspects of the subject to be most critically examined, and that all of us who have participated in it now view many of the details in an entirely different manner from that which we have hitherto regarded as the only possible one. Finally, we should like to express the hope that the revised views will be of an entirely optimistic nature regarding the future practicability of the use of electrical energy as the source of heat for the purposes discussed in the paper.

A MAGNETOSTRICTION ECHO DEPTH-RECORDER.*

By A. B. Wood, D.Sc., F. D. Smith, D.Sc., Associate Member, and J. A. McGeachy, B.Sc.

(*Paper first received 25th June, and in final form 31st October*, 1934; *read before the* Wireless Section *2nd January*, 1935.)

Summary.

A new system of echo depth-sounding is described in which the sound signal is produced and the echo received by high-frequency magnetostriction oscillators. Directional properties are given to these oscillators by means of suitable reflectors directed towards the sea-bed. The echo generates in the receiver high-frequency currents, which are amplified and passed through a chemical recorder. The motor driving the recorder also controls the instant of transmission of the sound signal so that the movement of the recording stylus is synchronized with the regular sequence of sound signals.

Whilst the sound signal travels to the sea-bed and back to the ship, the recording stylus traverses a proportionate distance over the chemically prepared recording paper. Two stains are recorded at each traverse, one corresponding to the zero instant of transmission and the other to the instant of arrival of the echo. As the ship proceeds on its course, a continuous record is made which delineates the cross-section of the sea traversed by the ship.

Records are reproduced to illustrate the performance of the apparatus in a laboratory tank and at sea. Good results have been obtained at depths exceeding 400 fathoms. The system is particularly suitable for sounding in very shallow water: a depth of 1 or 2 ft. can be clearly recorded.

(1) Introduction.

At the present time there are in existence several types of marine echo-sounding devices in regular use. Some of these may be described more particularly as depth *indicators*, whilst one or two not only give isolated indications of the depth of the sea but also provide a more or less continuous record of the sea-bed.

Echo-sounding devices may conveniently be divided into two main classes:—

(*a*) Low-frequency (sonic) systems, and

(*b*) High-frequency (supersonic) systems.

Of these, the British Admiralty system is of the low-frequency type.† Recently this system was fitted with an electrochemical recorder,‡ similar in principle to that described in the present paper but differing in mechanical features. The only high-frequency system which has hitherto attained commercial importance uses the supersonic vibrations of a quartz piezo-electric oscillator. This system, devised by Prof. Langevin and M. Chilowsky, has been developed commercially in this country by the Marconi Sounding Device Company.§ These two echo depth-sounding systems are now sufficiently well known to render further detailed reference to them unnecessary.

The present paper is concerned with a description of an entirely new type of high-frequency echo depth-recorder which possesses important advantages over the two types mentioned above.

It is desirable to explain that this new system of echo sounding was devised to meet a definite requirement which could not be met by any system then in existence.† This requirement involved the production of an echo depth-sounding apparatus to give a continuous record of the depth of water beneath a survey motor-boat of draught about 2 ft., travelling at full speed. A depth range of 0 to 200 ft., with an accuracy of about 1 ft., was specified. The first attempts were made with a modified form of the Admiralty pattern depth-sounder of the sonic type. The modified apparatus gave promise in a large tank at the Admiralty Research Laboratory but proved less satisfactory when tested at sea because of extraneous noises due to engine, propeller, and splashing water, which almost completely masked the relatively weak echo from the sea-bed. Furthermore, a serious practical difficulty arose in connection with the screening of the receiver from the transmitter. This was due to the fact that the wavelength in water of the low-frequency sound was comparable with the dimensions and draught of the boat, an unduly large proportion of the emitted sound consequently reaching the receiver by diffraction. These difficulties are inherent in all low-frequency systems and it was therefore considered preferable to avoid them by the use of a high-frequency system rather than to attempt to evolve expedients for overcoming them.

(2) Description of the New System.

After experimenting with various types of high-frequency sound sources suitable for use under water it was finally decided to employ a principle which had hitherto found little practical application, viz. magnetostriction. The adoption of this principle arose out of some preliminary experiments dating from 1925 carried out in H.M.S. "Vernon" by Dr. E. P. Harrison, who also collaborated with the authors in the early stages of development of the magnetostriction oscillator. The detailed design and construction of high-frequency magnetostriction transmitters and receivers will receive attention later in the paper, but for the present we shall consider only the general application to depth sounding.

The general arrangement is illustrated diagrammatically in Fig. 1. Two magnetostriction oscillators, a transmitter and a receiver, are mounted side by side in water-filled tanks and fitted in a chosen position in the motor boat. The transmitter is excited into resonant vibration at regular intervals of time, depending on the range of depth to be recorded. These sound impulses are timed by means of suitable motor-driven contacts which synchronize with the traverses of the recording point across the record. The sound impulse may be either a damped train of high-frequency oscillations or a short signal of constant amplitude obtained from a convenient source of alternating current. The short train

* British Patent No. 375375. † See Reference (1).
‡ Capt. A. J. L. Murray and N. Shuttleworth, British Patent No. 329403.
§ See Reference (2).

† The experiments began towards the end of 1929.

of high-frequency sound waves is directed vertically downwards to the sea-bed, whence it is reflected back to the magnetostriction receiver. Here the high-frequency pressure fluctuations are converted into corresponding alternating currents. These currents are amplified, rectified, and passed through the recorder. The latter is driven by the motor which controls the transmitting contacts, and the recording point is so arranged that its zero position on the record coincides with the instant of transmission of the sound impulse. While the sound impulse is travelling from the transmitter to the receiver

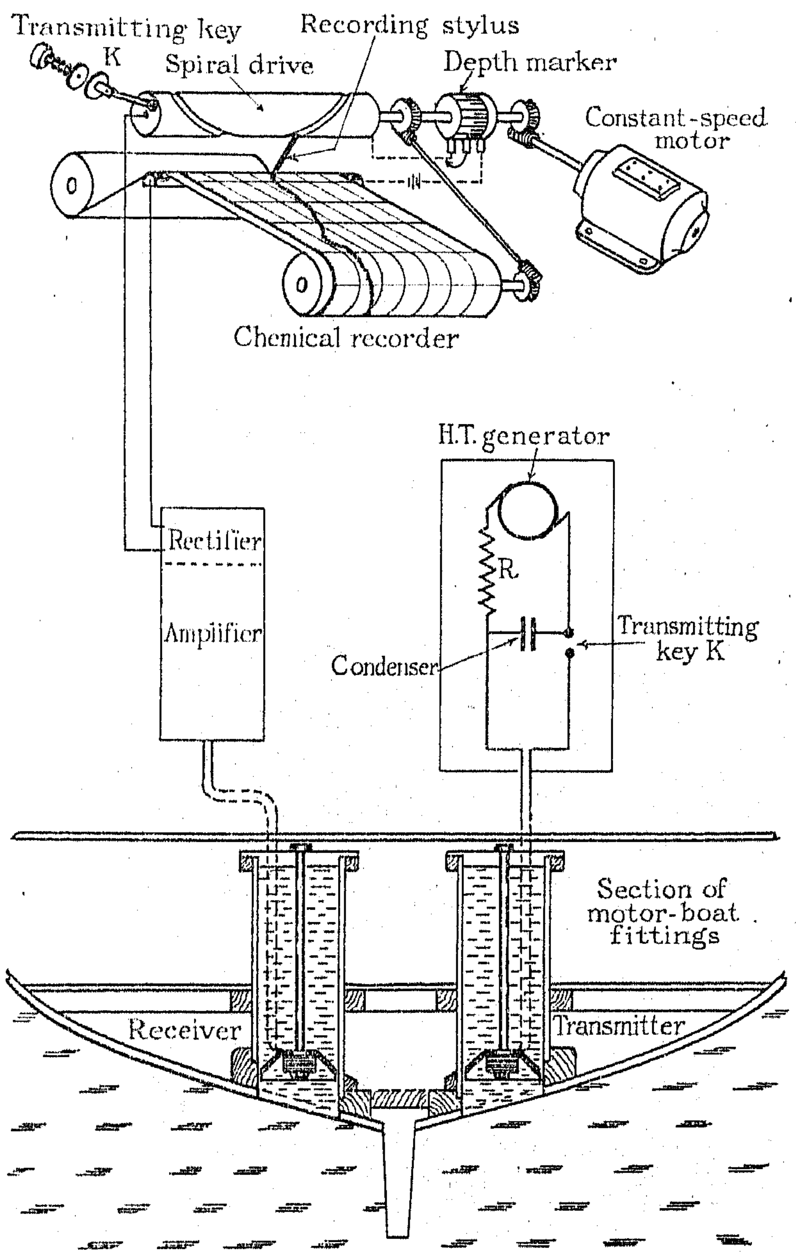


FIG. 1.—Magnetostriction echo depth-recorder. General arrangement.

via the sea-bed the recording point has travelled a corresponding distance from left to right of the paper. Various types of recorder have been used but a chemical recorder* has hitherto proved most satisfactory, especially at the relatively high speeds of recording required in very shallow water. In the chemical recorder a small electrical current produces a stain on a chemically treated paper. Two such stains are, in general, produced at each traverse of the recording point, the first at the instant of transmission (the zero) and the second on the arrival of the echo. As the paper is slowly fed forward in a direction at right angles to the traversing point, two stained bands are obtained, one of which represents the zero or sea surface whilst the other represents the sea-bed. A continuous record is thus obtained of the contour of the sea-bed as the ship proceeds on its course. The width of the zero band is determined by the sound reaching the receiver either by diffraction or by transmission through the hull. This band is of appreciable width; it is, however, less intense than the echo band in very shallow water. In order to record very shallow depths it is therefore sufficient to reduce the sensitivity of the amplifier. Figs. 15 and 17(a) (see Plate 3) show records so obtained.

An auxiliary commutator is used to produce a depth scale on the record, a series of equidistant dots representing known depth intervals being recorded at each traverse of the recording point.

As already stated, the apparatus was originally designed for recording depths from 0 to 200 ft., but the method has also proved satisfactory in depths exceeding 400 fathoms.

* Capt. A. J. L. Murray and N. Shuttleworth, British Patent No. 329403.

(3) THE MAGNETOSTRICTION OSCILLATOR—TRANSMITTER AND RECEIVER.

Some ferromagnetic materials possess the properties of changing their linear dimensions when subjected to a magnetic field (the Joule effect) and conversely of changing their magnetic condition when mechanically strained (the Villari effect). These properties have formed the subject of research by numerous investigators* in a wide range of alloys, especially the alloys of iron, nickel, and cobalt. A series of curves† for various materials showing the fractional change of length dl/l with magnetic field is shown in Fig. 2. The form of this curve varies from one material to another, and with the previous thermal and mechanical treatment. The curves in Fig. 2 show clearly that annealed nickel and cobalt steel give the largest magnetostriction effects within the limits of 0 to 100 gauss magnetizing field, that is, between the origin and the dotted line. For low values of H, soft annealed nickel is definitely superior to hard-rolled nickel.

(a) *Choice of Material.*

The selection of a suitable material for a magnetostriction oscillator is to a large extent determined by considerations of a practical nature. A compromise between various conflicting factors is necessary, bearing in mind that the oscillators must be reproducible in large numbers on a commercial scale. The material selected must possess as far as possible the following qualities:—

(1) Large magnetostrictive effects for relatively small magnetic fields.
(2) Simple and easily reproducible composition. [Alloys requiring exact proportions and exceptional heat treatment are therefore unsuitable, unless they possess a large compensation in (1) above.]
(3) Good mechanical properties. The material must be available in thin sheet and stampings and in the form of thin-walled tubes.
(4) High resistance to corrosion when immersed for long periods in water.

* A bibliography is given in papers by S. R. WILLIAMS (*Journal of the Optical Society of America*, 1927, vol. 14, p. 383), and L. W. MCKEEHAN (*Journal of the Franklin Institute*, 1926, vol. 202, p. 737).
† See Reference (3).

Combining these desirable qualities, nickel of ordinary commercial purity appears to be the most suitable magnetostrictive material for the purpose: it is simple in composition and easy to anneal; it has good mechanical properties and can be readily obtained as thin sheets, tubes, or stampings; and it has a high resistance to corrosion, remaining for long periods in water without sign of deterioration.

With regard to its magnetostrictive properties, nickel is, as we have seen in Fig. 2, one of the best materials obtainable. For small magnetizing fields it shows a large Joule effect, a contraction of the order 30 parts per million being observed for fields up to 100 gauss. The rate of change of length with magnetization is very large for small values of H. The maximum peak value of alternating sinusoidal stress which can be usefully obtained from nickel with an upper limit of field strength of 50 gauss is of the order of 400 lb. per sq. in. It is of interest to note that the corresponding stress produced piezo-electrically in quartz by an applied potential of 2 000 volts per cm is of the order of 4 lb. per sq. in.

Nickel has been chosen on these grounds for the magnetostriction oscillators described in this paper. Various alloys have been tried but as yet the results have not proved so satisfactory, for one or more of the reasons given above. In what follows, therefore, we shall be concerned with nickel magnetostriction oscillators.

(*b*) *Design of Oscillators—Cylindrical, Ring, and Strip Types.*

Fig. 2 illustrates the small changes of length observed in magnetostrictive rods or wires when subjected to steady magnetizing fields. If a magnetized rod is subjected to the action of an alternating magnetic field parallel to its length, mechanical oscillations at the frequency of this alternating field are set up; when this frequency coincides with the natural frequency of the rod in longitudinal vibration resonance occurs and a large increase in the amplitude of vibration results. Under these conditions of resonance the rod becomes more efficient as a source of sound. The phenomenon in this simple form is practically useless for the generation and reception of sound at high frequencies. In the first place, the eddy currents in the rod prevent the penetration of high-frequency alternating magnetic fluxes, and only a thin layer of the material on the outside of the rod is effective in producing vibrations. Again, the demagnetizing effect of the ends of short bars (of high longitudinal frequency) prevents the magnetic induction from attaining sufficiently high values. Consequently it is desirable that the magnetostrictive material should be constructed (*a*) of thin sheet or laminations, and (*b*) in the form of a closed magnetic circuit.

The first of these requirements appeared to present an almost insuperable difficulty. Thin laminæ are not usually regarded as capable of resonant vibration at high frequencies. Experiments have shown, however, that such laminæ, if not excessively thin, resonate reasonably well, the internal damping being small relative to that due to radiation damping when a pile of the laminæ is immersed in water. Motional impedance measurements with such a pile of annular nickel stampings show a high degree of resonance for radial vibration in air.* Similar measurements in water confirm that the internal mechanical damping of the laminæ is small compared with the radiation damping; the efficiency of conversion of electrical into mechanical energy is very good.

Various forms of these high-frequency oscillators have been constructed in accordance with the two principles mentioned above. It will be sufficient, however, if three of these are now described, all of which have given satisfactory service in echo sounding. In all cases the nickel is annealed at a temperature of approximately 1 000° C. To avoid excessive eddy currents the contiguous layers of nickel must be insulated from one another. This is done in numerous ways, two of which may be of interest. In the first of these the thin nickel

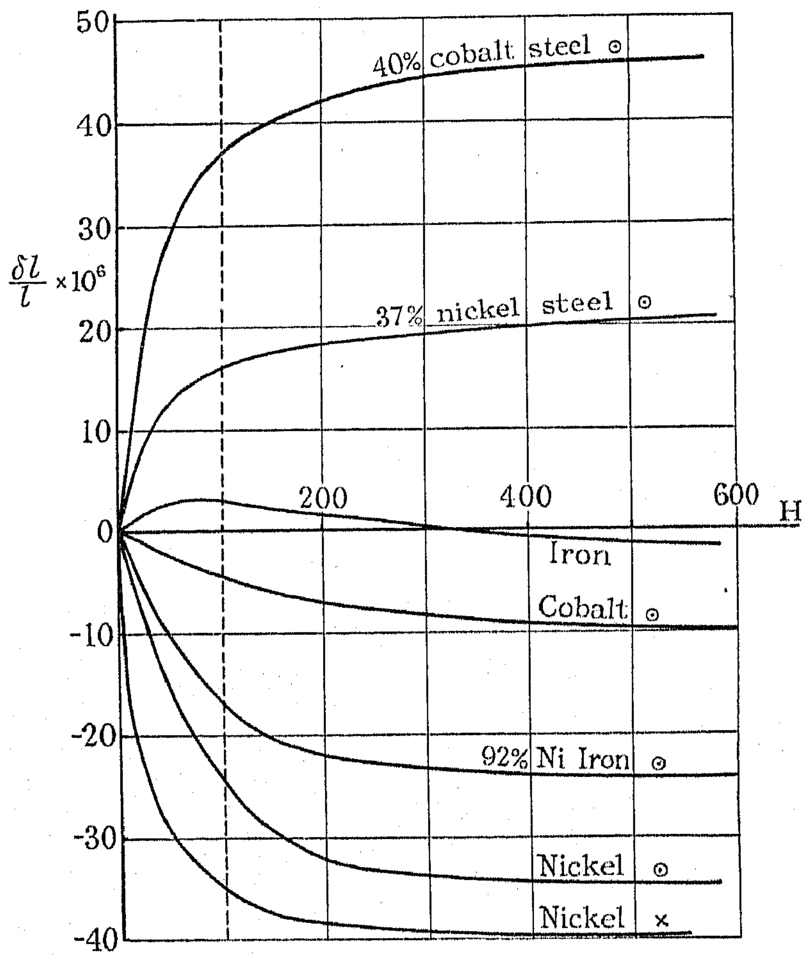


Fig. 2.—Magnetostriction in ferromagnetic materials.
⊙ ⊙ Honda and Kido. × × Yosio Masiyama.

sheet is oxidized by heating in contact with air in the furnace, either during or after the annealing process. This coats the annealed nickel with a thin film of greenish-black oxide which serves as a very effective electrical insulator. In addition to the property of electrically insulating the nickel layers from one another, the thin film of oxide also serves as some protection of the nickel from corrosion when in contact with water. In the second method the annealed nickel is coated with a suitable insulating varnish, which may be allowed to dry previous to the assembly of the oscillator or which may be applied wet during the assembly. In the latter case thin paper or similar solid insulator is also interleaved between the layers of nickel.

(i) *Cylindrical Oscillators, Scroll Type; Longitudinal Vibration.*—An example of this type of oscillator, con-

* See Reference (4).

taining about $0 \cdot 5$ kg of nickel, is illustrated in Fig. 3. It is constructed by winding tightly on a mandrel long strips of nickel sheet and thin paper coated with cement. The hollow cylinder thus formed is consolidated by baking at an appropriate temperature. A load attached to one end serves to tune the oscillator to the desired frequency and to increase the area of vibrating surface in contact with the water. Such an oscillator is found to be sufficiently resonant mechanically and exhibits good magnetostrictive properties at supersonic frequencies. The only winding necessary consists of about 10 turns of low-resistance wire wound toroidally through the nickel cylinder as shown. Current through this winding produces circumferential magnetization which results in simultaneous changes in the length, diameter, and thickness, of the nickel cylinder; the volume remains sensibly constant. Since it is desired to excite longitudinal resonant vibration the appropriate frequency of alternating current must be supplied. A converse process, involving the Villari effect, takes place when the oscillator is used as a receiver.

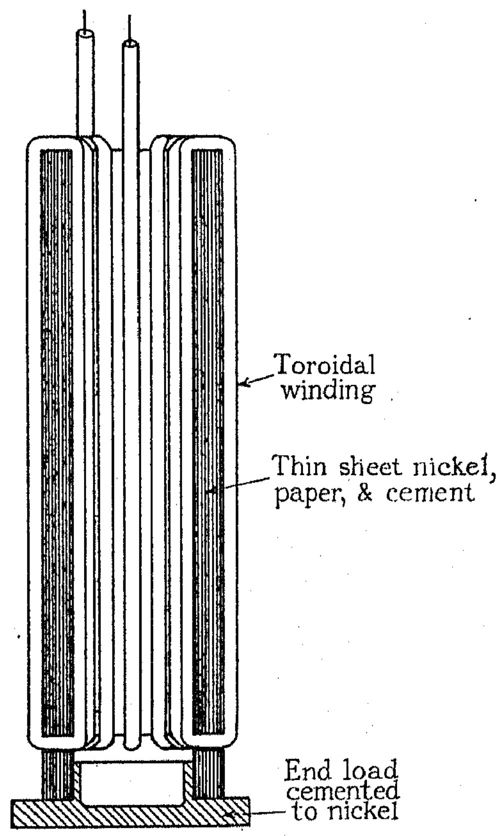


FIG. 3.—Cylindrical scroll-type oscillator.

(ii) *Ring Oscillators; Radial Vibration.*—This form of magnetostriction vibrator is a cylindrical pile of annular nickel rings (say $0 \cdot 002$ to $0 \cdot 005$ in. thick). These may be consolidated to form a solid resonant block by coating with a suitable insulating cement and baking under pressure. Alternatively, the laminations may be built up loosely into a pile so that they are free to vibrate individually and more or less independently. It is important, however, in the latter form of construction to obtain a reasonable uniformity between the individual laminations. This is achieved by stamping the annular rings from thin nickel sheet and "shuffling" a large number of such stampings to obtain an average in each oscillator and to avoid progressive errors in diameter due to the wear of the stamping tools. The fundamental frequency f of radial vibration of a circular annulus, of width small compared with the diameter, is given by

$$f = \frac{v}{\pi d}$$

where v is the velocity of sound in the material and d is the mean diameter of the annulus. For example, a ring of mean diameter 10 cm resonates in this mode at a frequency $f = 15\,900$ cycles per sec. A series of equidistant holes spaced round the periphery of the stampings

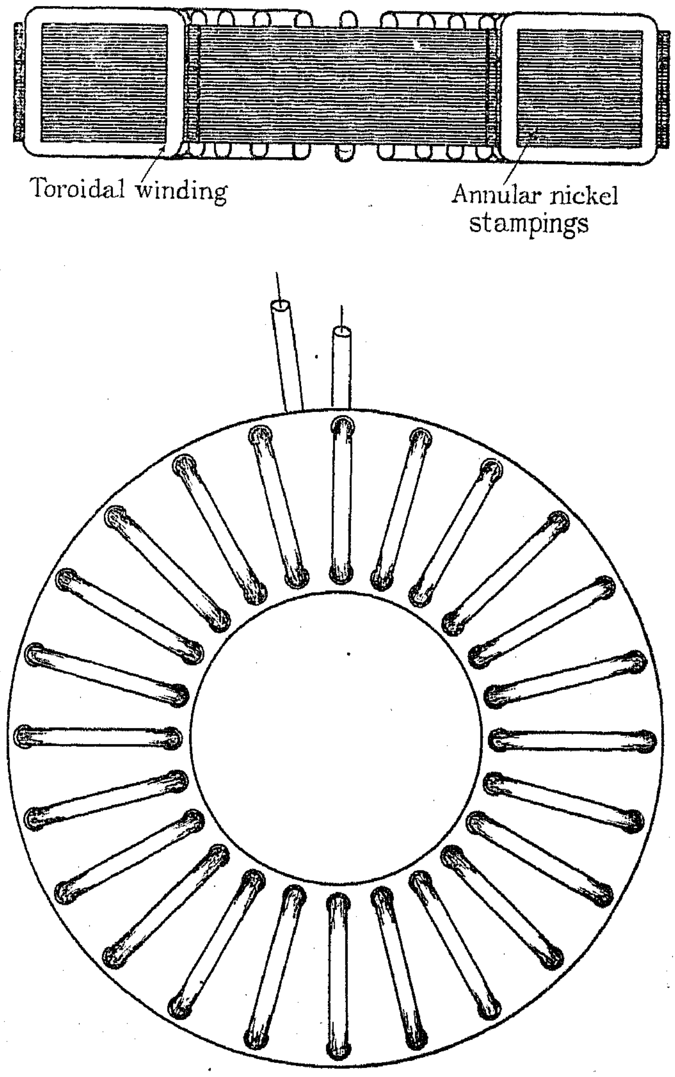


FIG. 4.—Ring-type oscillator.

accommodates the toroidal winding. This arrangement leaves the sound-emitting surface, i.e. the edge of the stamping, free from obstruction. The circular magnetization produced by current in the toroidal winding results in a small change in the diameter of the magnetized ring, the amplitude of this change reaching its maximum value when the frequency of the magnetizing current coincides with f, the fundamental radial frequency of the annulus.

An example of this form of vibrator is shown in Fig. 4. It contains about 3 kg of nickel stampings each $0 \cdot 002$ in. thick. The outer cylindrical surface constitutes the active sound-emitting surface in contact with the water. To prevent sound emission in opposite phase from the inner cylindrical face, the latter is covered with a layer of rubber mousse* or an equivalent air-filled space. The radiation damping of this form of oscillator may be con-

* Rubber mousse or expanded rubber froth is composed of small, watertight air cells.

trolled by varying the ratio of the surface area exposed to the water and the mass of nickel.

The mean diameter of the annulus is determined by the frequency required, while the radiation damping is controlled by the width of the ring. If a very large amount of damping is required with a given amount of nickel the cylindrical pile of stampings becomes relatively long and narrow, whereas for relatively small radiation damping the pile should be short and wide. The proportions shown in Fig. 4 have given good results in practice.

(iii) *Strip Oscillators; Longitudinal Vibration.*—A third form of oscillator is shown in Fig. 5. The thin nickel stampings are rectangular in shape and consist essentially of two nickel strips connected by two tuning legs. The longitudinal members which connect the tuning legs may, with sufficient accuracy, be regarded as loads and the legs as springs. By varying the length and width of the legs and the depth of the end loads, any desired frequency can be obtained. These rectangular nickel stampings are annealed, oxidized, or coated, in a similar manner

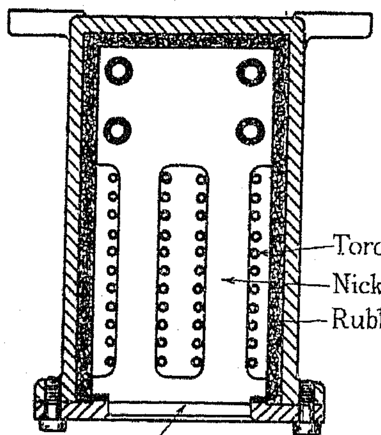


FIG. 5.—Section through strip oscillator.

to the circular stampings. They are insulated from each other and mounted to form a rectangular block of the required size. The magnetizing coils are wound around the tuning legs, which form part of the closed magnetic circuit. As in (ii) the edges of the stampings constitute the active sound-emitting surface in contact with the water, the opposite vibrating edges being screened as before by means of an air cavity, e.g. a layer of rubber mousse. The rectangular block of stampings is mounted in a suitable casing, not necessarily watertight, which may be lined with rubber mousse.

It should be observed that in most of these forms of magnetostriction oscillator it is possible to permit free access of water to the surfaces of the nickel and the associated windings.

(c) *Air Reflectors. Angle of Sound-beam.*

In order to obtain sufficient "directionality" in the magnetostriction transmitter and receiver, the oscillators just described, more particularly types (i) and (ii), must be mounted in some form of reflector. The semi-angle of the primary conical beam of sound emitted from a circular source of diameter D is given by

$$\theta = \text{arc}\sin(1\cdot22\lambda/D)$$

where λ is the wavelength of sound in the medium under consideration.* Consequently, at a particular frequency, e.g. 15 kilocycles per sec. ($\lambda = 10$ cm in water), the angle of the primary beam of sound is fixed by the effective diameter of the source; analogous considerations apply also to the directional properties of the receiver. The sound energy from a source of diameter large compared with a wavelength of the sound emitted is confined to a relatively narrow cone. This is an advantage from the point of view of economy of sound energy; but in its practical application to echo sounding a very sharply

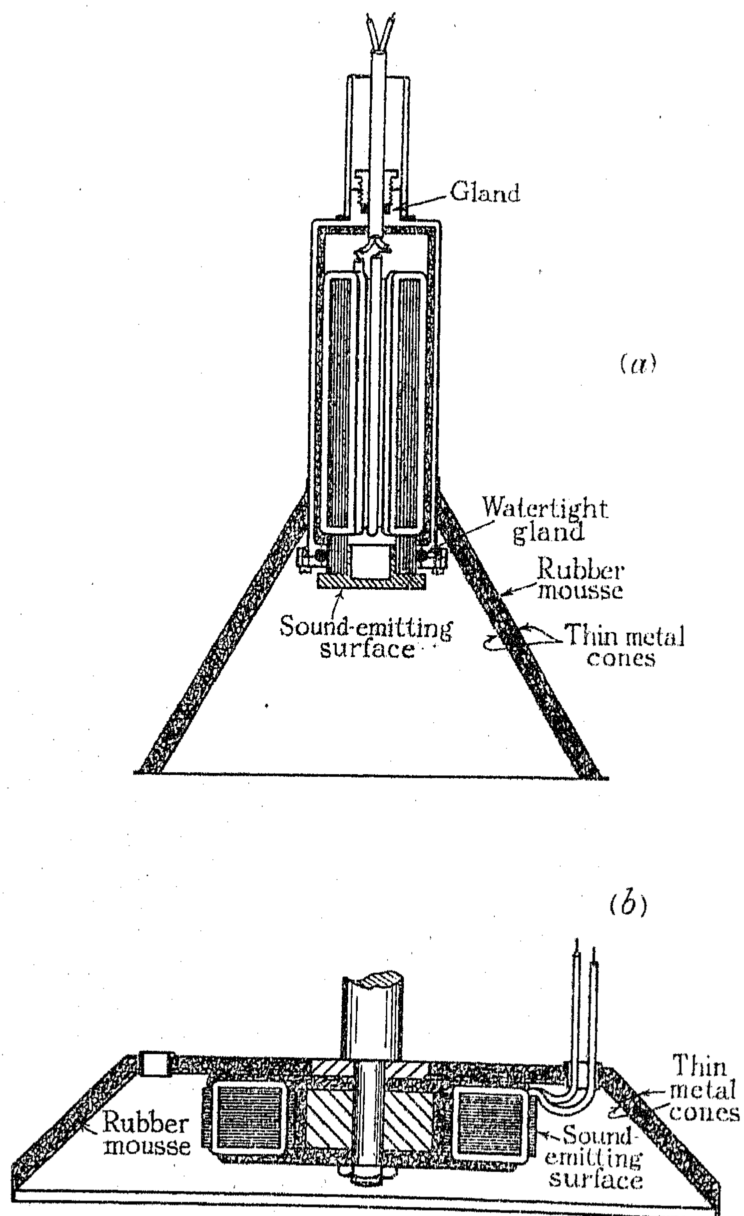


FIG. 6.—Scroll and ring oscillators mounted in conical reflectors.

directional transmitter and receiver may result in a loss of some of the echoes, particularly in a moving ship and over a rapidly shelving or undulating sea-bed. The choice of the angle of the beam is therefore a compromise.

With the cylindrical and ring type oscillators described above, an increase in effective diameter is obtained by means of a reflector, since the dimensions are too small to ensure sufficiently good inherent directional properties. Air is the best reflecting medium for use under water, a relatively thin layer producing total reflection. Two types of reflectors which have given good service are shown in Fig. 6. In both of these the reflector is formed by a pair of thin conical metal spinnings enclosing an air cavity. The double-walled enclosure is made watertight,

* See References (5) and (6).

but to avoid failure of reflecting properties in case of leakage the cavity is filled with rubber mousse, which may be regarded as equivalent to air alone. The theoretical directional curve* for type (*b*) reflector is shown in Fig. 7. The semi-angle of the primary cone of sound is about 20° with an oscillator of frequency 15 kilocycles per sec. The beam angle of the smaller type (*a*) is somewhat greater on account of its smaller diameter.

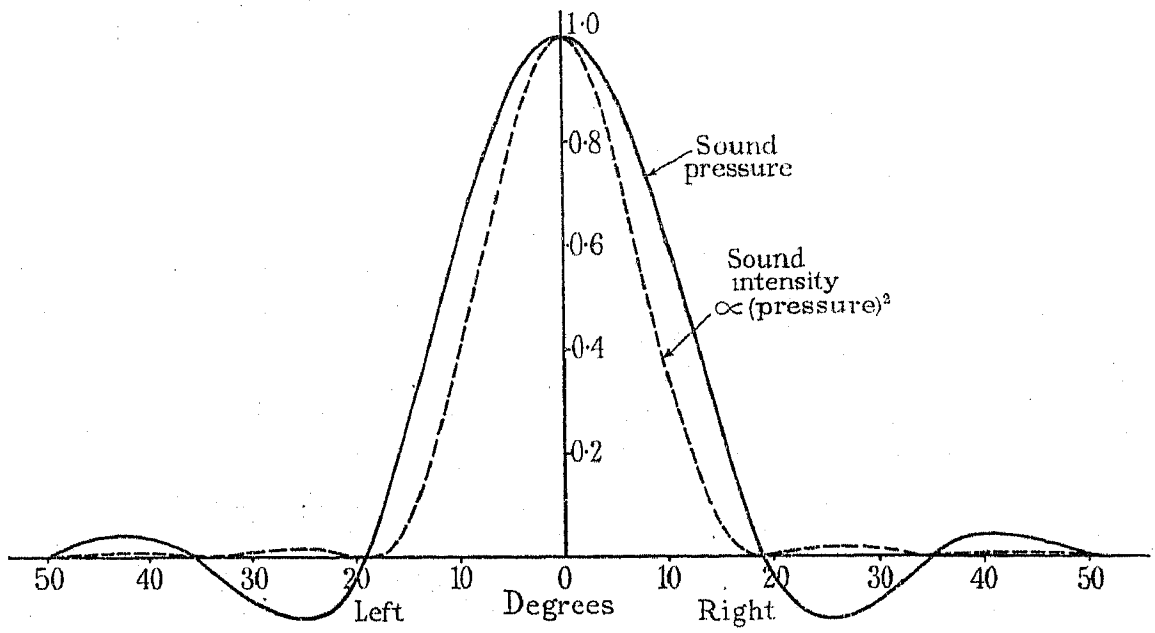


FIG. 7.—Theoretical sound-distribution curve of ring-type oscillator (15 kilocycles per sec.) with 12 in. dia. reflector.

(4) THE TRANSMITTER. METHODS OF EXCITATION. THE RECEIVER.

As already mentioned, the magnetostriction oscillators described may be used either for generation of high-frequency sound energy or conversely for reception. One oscillator may be used both for the transmission of the sound and for the reception of the echoes by incorporating a suitable send-receive switch system in the apparatus whereby the magnetostriction oscillator is automatically switched from a transmitting circuit to a receiving circuit. It is more convenient, however, particularly in very shallow-water sets, to use independent transmitters and receivers, and in what follows we shall confine our attention to such arrangements.

Various methods have been used to excite resonant high-frequency vibration in the transmitter. Two of these which have given good results in practice are conveniently described as (*a*) damped-impulse transmission and (*b*) continuous-wave transmission.

(*a*) *Damped-Impulse Transmission.*

This method is illustrated in Fig. 8. A condenser C is charged through a current-limiting resistance R from a supply voltage V, the key K being then in position 1. At a predetermined time the key switches over to position 2 and the condenser discharges through the low-resistance winding of the magnetostriction oscillator. This produces a heavily-damped high-frequency alternating current in the oscillator circuit. The frequency and amplitude of this current are given approximately by the usual relations between the capacitance, inductance, and resistance, of the circuit. In this method it is found that little advantage is gained by supplying the nickel with an additional steady magnetization. The optimum value of the capacitance C is that which tunes the transmitting circuit to a frequency half that of the mechanical resonance of the nickel oscillator. Under these conditions the inductance of the circuit varies with the instantaneous value of the current, and an average value must be taken as sufficiently accurate. The energy stored in the condenser and discharged through the winding of the magnetostriction oscillator at each transmission is

$\frac{1}{2}CV^2$ joules (if C is measured in farads and V in volts).

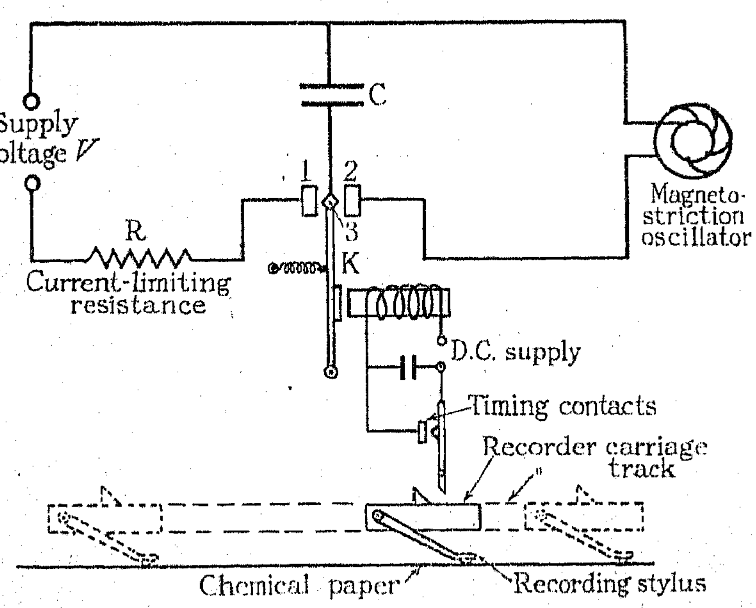


FIG. 8.—Damped-impulse transmission.

Sound output increases with increase of both C and V, more particularly the latter. As we have just seen, however, the optimum value of C is fixed by the frequency f and inductance L of the oscillator. By reducing the number of turns in the winding, thereby reducing the inductance, it is possible to increase C, but a practical limit is soon reached in this direction owing to losses in connecting cables. Transformers give some improve-

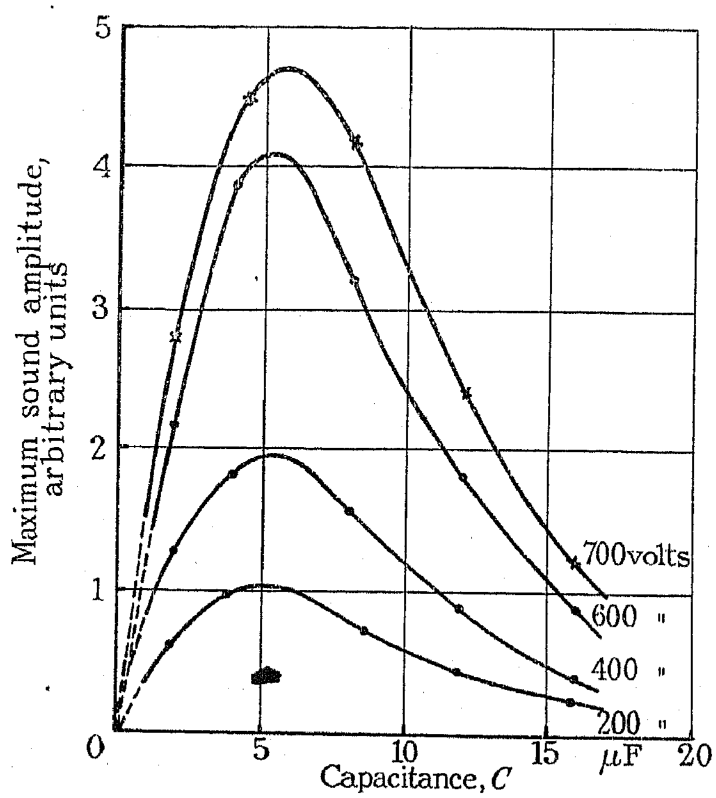
* See Reference (6).

ment, but the simple direct circuit shown has given very good results without such additions. The effect of varying the capacitance C and the voltage V is illustrated in Fig. 9. The ordinates represent in arbitrary units the peak value of sound amplitude observed in the water at 32 ft. from the transmitter, and the abscissæ represent capacitances. The tuning effect produced by a capacitance of 5 or 6 μF is clearly shown. The increase of sound amplitude with increase of voltage is rather more rapid than the simple linear law which might have been anticipated. This is due to the fact that the relation between the magnetostriction strain and the applied magnetizing field is not linear.

The effective resistance of the magnetostriction transmitter, deduced from oscillograph records, is of the order of 1 or 2 ohms only at frequencies in the neighbourhood of 15 kilocycles per sec., most of which is due to eddy-current and hysteresis loss in the nickel. When a condenser of 6 μF capacitance charged to 1 000 volts is discharged through such a low resistance, large instantaneous currents are developed.

Cathode-ray oscillograph records, examples of which are reproduced in Fig. 10 (Plate 1), confirm this conclusion, peak currents of several hundred amperes being observed. The records show the complex nature of the wave-form and the rapid decay of the oscillations. Practically the whole of the energy stored in the condenser is discharged during the first cycle. The importance of reducing the effective resistance of the circuit will thus be realized. This has been achieved as far as practicable by the use of thin annealed nickel stampings and a special type of transmitting key. One form of the latter is shown in Fig. 11; copper contacts of large area discharge the condenser through the winding of the magnetostriction oscillator. These contacts (about 1 in. diameter) are arranged to meet with parallel faces at a fairly high speed (about 5 ft. per sec.). In this way the resistance is kept down to a low value and sparking is very slight even at 1 000 volts. When it is desired to fit the magnetostriction transmitter on the hull of a large ship, with the control switchboard and recorder at some remote point, the resistance of leads is minimized by mounting an electromagnetic key (with condenser) as near as possible to the magnetostriction transmitter. This arrangement is then operated from small auxiliary timing contacts mounted on the depth recorder as shown in Fig. 8. The recorder carriage closes these contacts in its travel from right to left of the diagram, but not in the reverse direction.

The form of the electrical oscillations in the receiving circuit is shown in the cathode-ray oscillograph records (series B) in Fig. 10. When a tuned magnetostriction oscillator is used in conjunction with a tuned circuit, the peak value of received current is attained after 0·001 sec. approximately, which corresponds to an echo range of 2½ ft.



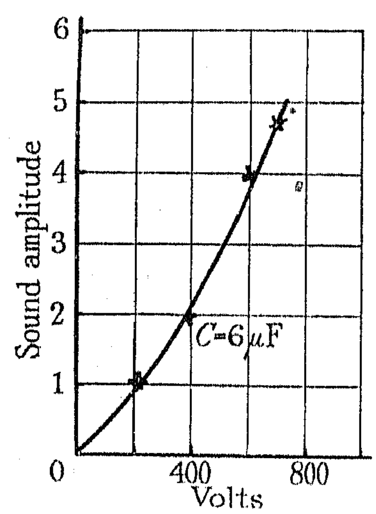
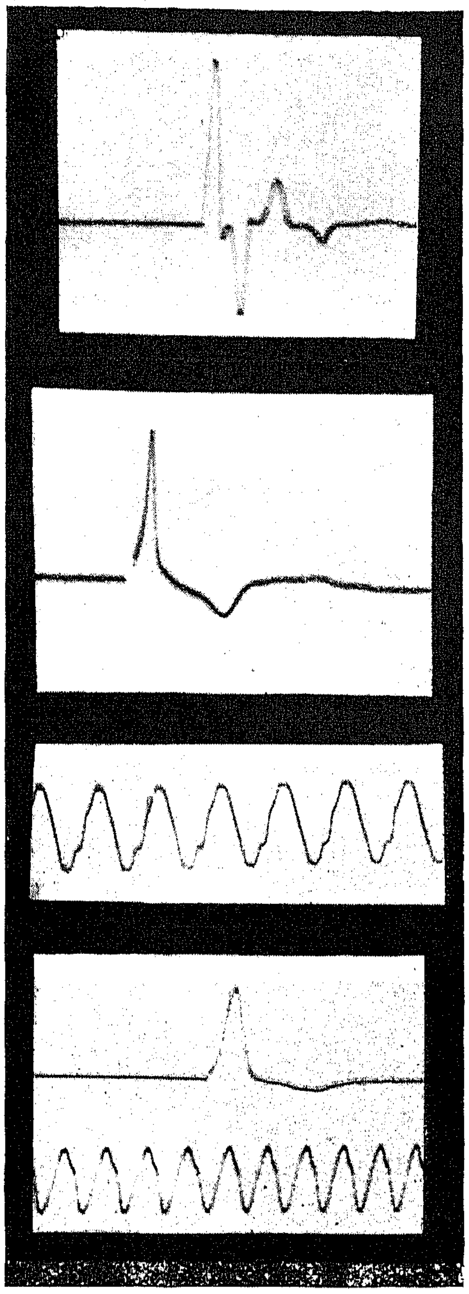


FIG. 9.—Variation of sound amplitude with capacitance and voltage. (Ring oscillator, 15 kilocycles per sec., in 12 in. dia. reflector.)

(*b*) *Continuous-Wave Transmission.*

A useful alternative to the condenser-discharge method of exciting the magnetostriction transmitter, which should prove valuable in extending the magnetostriction method of echo sounding to greater depths, may conveniently be described as the continuous-wave method. The principle is illustrated in Fig. 12. The short, heavily-damped oscillatory current impulse of the condenser discharge is replaced by a short " dot " (lasting, say, 0·02 sec.) of alternating current of relatively constant amplitude. In this case it is desirable to magnetize the nickel oscillator by means of an auxiliary d.c. circuit containing a choke coil as shown in Fig. 12. The superposed alternating current adjusted to the resonant frequency of the magnetostriction transmitter may be



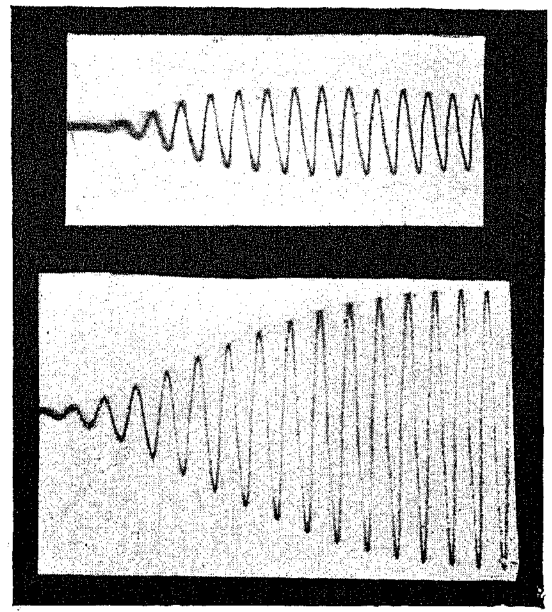
(1) Cylindrical scroll oscillator (16 kilocycles) as used in Moray Firth experiments. 10 μF; 725 volts; peak current 870 amps.

(2) Ring oscillator (16 kilocycles) as used in Stornoway experiments. 10 μF; 400 volts; peak current 240 amps.

(3) Time scale for records (1) and (2). 10 kilocycles per sec.

(4) Ring oscillator (15 kilocycles). 32 μF; 400 volts; peak current 500 amps.; time scale 10 kilocycles per sec.

(*A*) Form of current impulse transmitted.



(1) Ring oscillator (15 kilocycles). Receiver mechanically untuned. Electrical circuit tuned.

(2) Ring oscillator (15 kilocycles). Receiver mechanically tuned. Electrical circuit tuned.

(*B*) Form of electrical impulse received.

FIG. 10.—Cathode-ray oscillograph records.

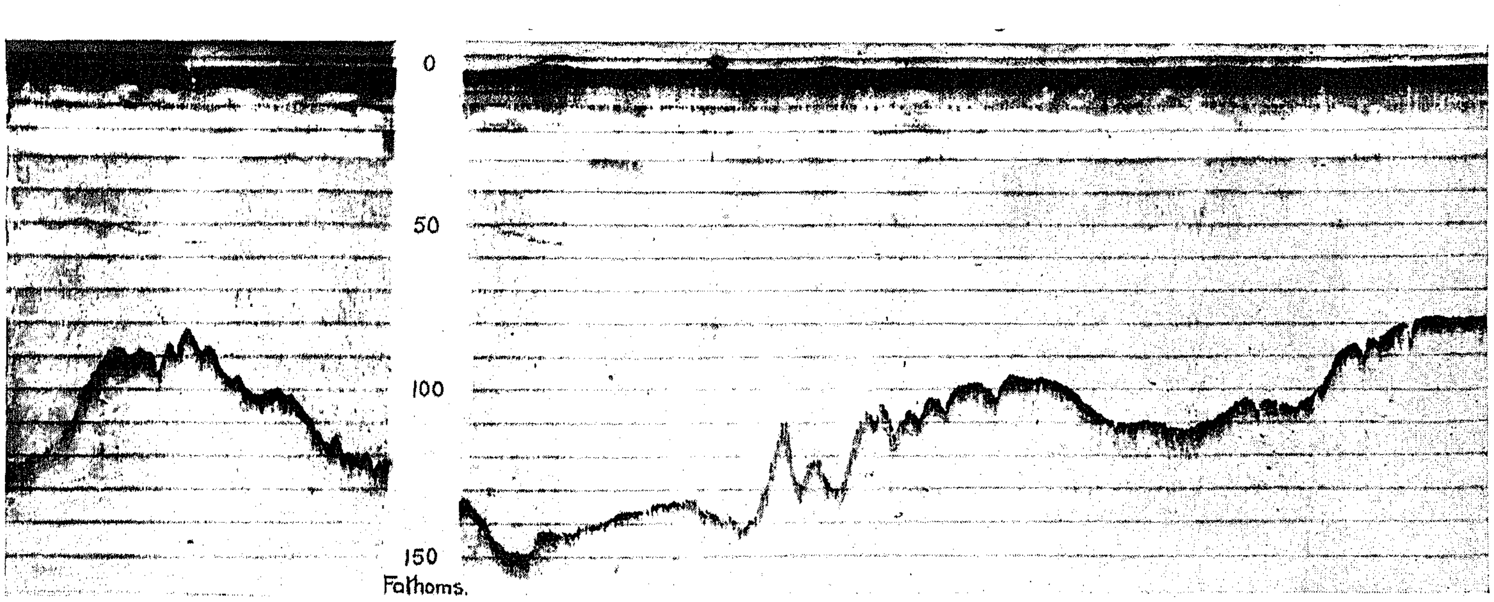


FIG. 19.—Ring oscillators (inboard). Damped-impulse transmission. [Ship speed 10 knots; paper speed 0·2 in. per min.]

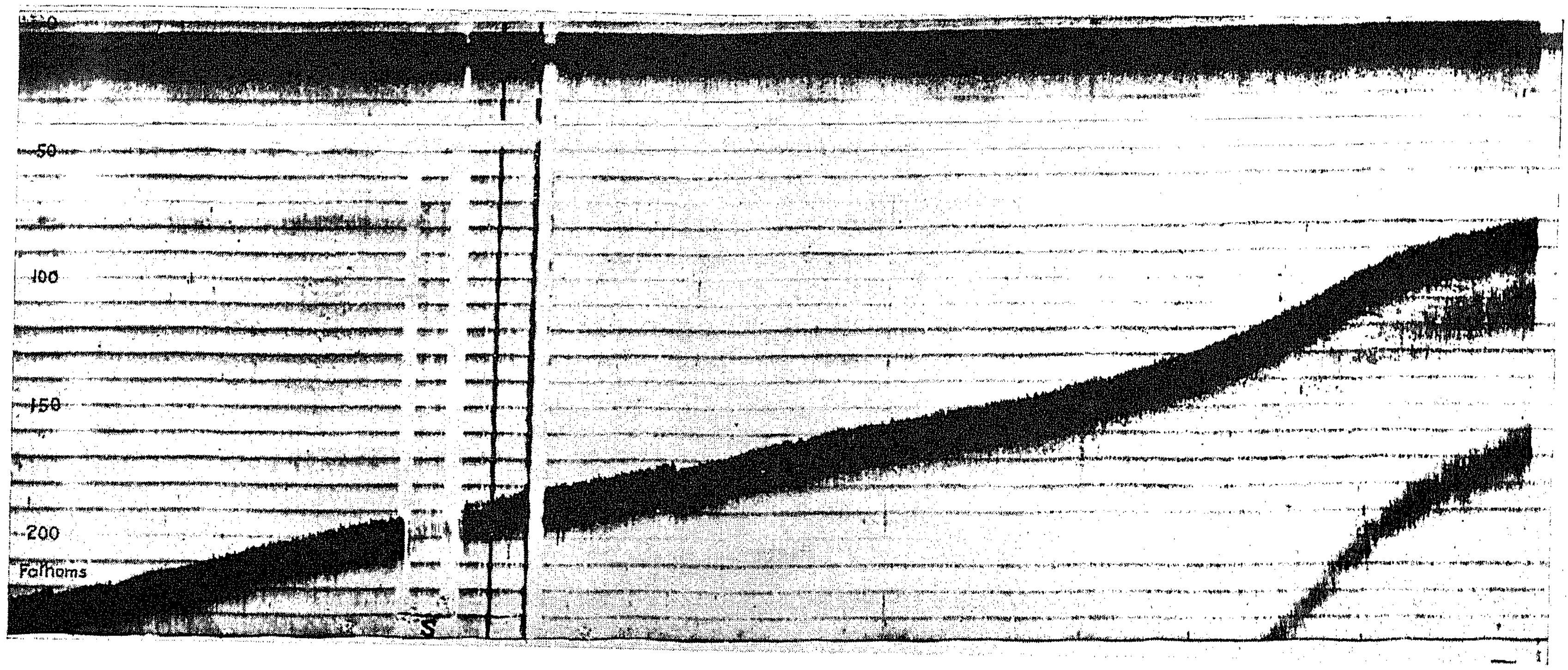


FIG. 22.—Ring oscillators (outboard). Continuous-wave transmission. [Ship speed 4 knots; paper speed $0 \cdot 2$ in. per min.]

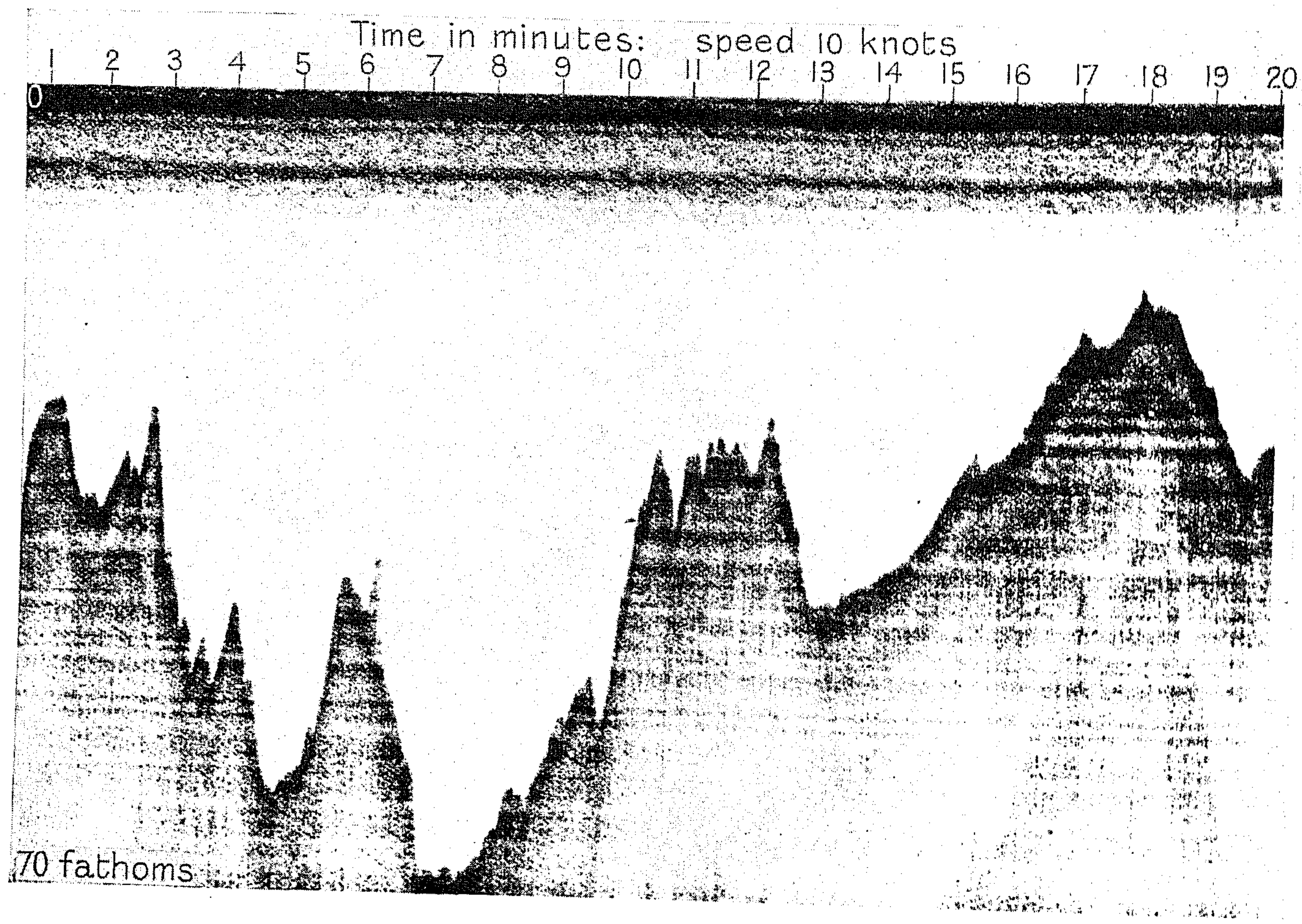


FIG. 23.—Record made by Grimsby trawler "Glen Kidston" near Bergen. Damped-impulse transmission.

obtained from a valve oscillator (as illustrated in Fig. 12). The transmitting key now connects the a.c. supply for the required short time-interval, and a corresponding short train of high-frequency sound of approximately uniform amplitude is emitted by the transmitter.

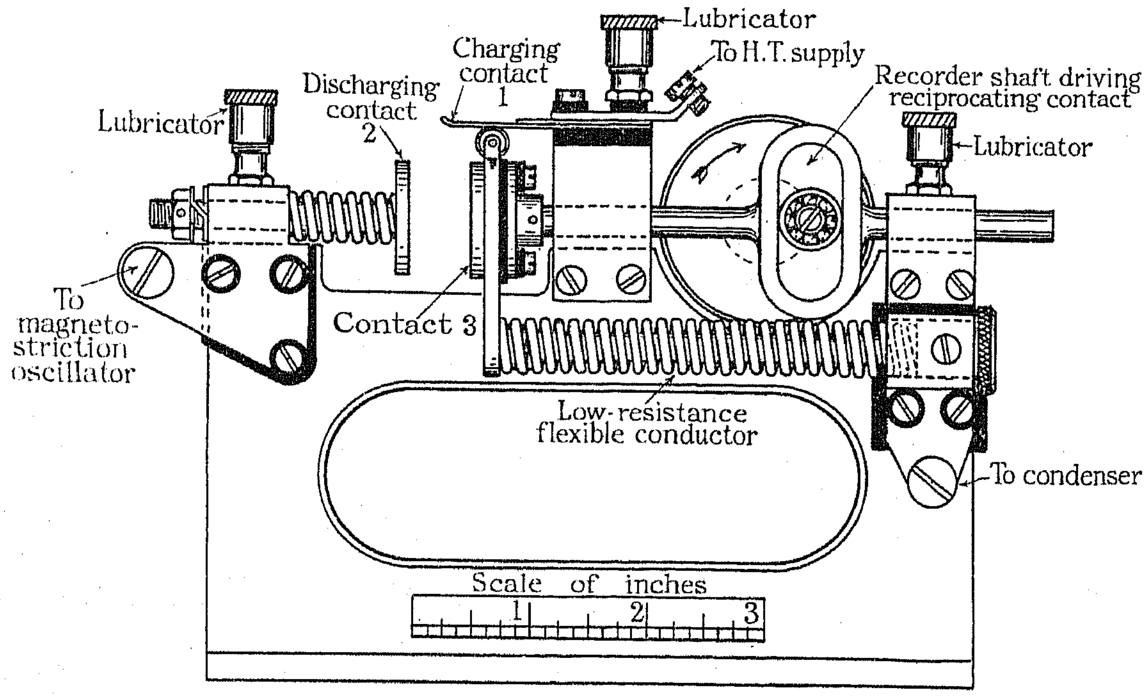


FIG. 11.—Details of transmitting switch.

(c) The Receiver.

As already stated, magnetostriction receivers are identical in construction with transmitters. They are built up of the same thin nickel stampings wound with a few turns of low-resistance insulated wire and are mounted in similar air-filled reflectors to obtain the desired directional properties. Since both transmitter and receiver are highly directional, they may be mounted side by side in the bottom of a ship without risk of serious interference by direct sound. Both transmitter and receiver face the sea bottom, and the receiver is consequently sensitive to high-frequency sound approaching from this direction only.

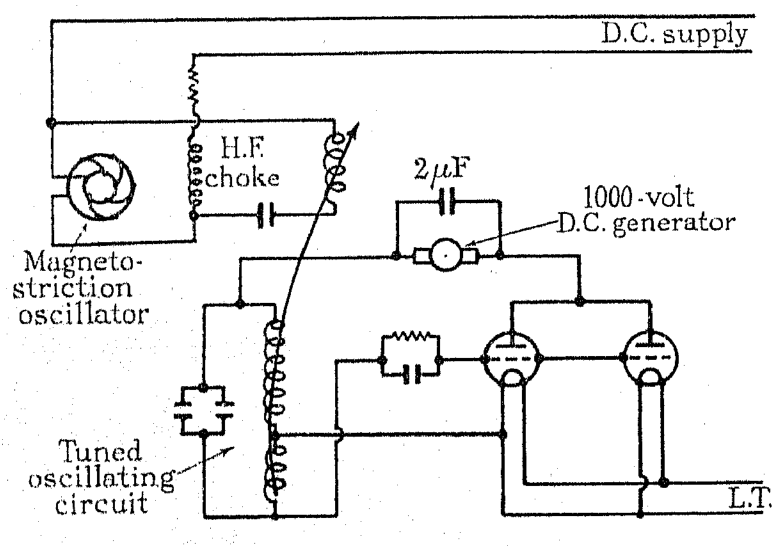


FIG. 12.—Continuous-wave transmission.

The sensitiveness of the receiver is dependent on its initial state of magnetization. Since the magnetic circuit through the nickel is closed, any residual magnetization may be regarded as "permanent." Consequently when once the circular magnetization of the stampings has been produced by means of a direct current through the windings, further use of the current is unnecessary. The process of magnetization is carried out by passing a large current momentarily through the toroidal winding of the magnetostriction receiver. When once magnetized in this way the receiver retains its sensitiveness. The frequency of the receiver must of course be the same as that of the transmitter and it is therefore usual to assemble both from the same batch of nickel stampings.

(5) THE AMPLIFIER-RECTIFIER.

The small electromotive forces developed in the magnetostriction receiver are amplified by means of a step-up transformer with tuned secondary winding. The output from this tuned circuit is applied to the grid of the first valve of an amplifier. In these days the choice of amplifier is extensive and it is unnecessary to go into much detail. A suitable pattern of resistance-capacitance-coupled amplifier is illustrated in Fig. 13. This type has three or four stages of amplification with a step-down output transformer and a full-wave type of copper-oxide rectifier.

In echo depth-recorder sets for very shallow water the small generator used to charge the transmitting condenser also supplies current to the plate circuits of the valve amplifier. The direct current from the copper-oxide rectifier passes through the platinum recording stylus (positive) and the aluminium recording bar (negative) of the chemical recorder.

A thyratron valve has also been used with success as a relay interposed between the amplifier and the recorder. This arrangement is most advantageous when the chemical recorder is replaced by some other type, e.g. an inked-thread recorder.

(6) THE RECORDER.

Experiments have been made with various types of recorder, but the one giving most satisfactory results is

that in which small electrical currents produce a stain on a chemically prepared paper.* A large selection of chemicals is available for such a purpose, one of the best being a solution of potassium iodide and starch. The paper, soaked in this solution, is used in a slightly moist condition. The stain produced by the current has a brownish-purple colour which changes to a definite brown on drying.

The form of recorder preferred for short-range echo detection is shown in Fig. 14 (Plate 2) and diagrammatically in Fig. 1. This recorder is driven from a small electric motor fitted with a governor to ensure constancy of speed. A pair of timing contacts are provided which may be used either as the actual transmitting contacts or as auxiliary contacts for the operation of a separate electromagnetic transmitting key. The recording stylus is carried on a traveller which engages with a helical groove cut in the surface of a cylinder geared to the main drive. Rotation of the cylinder produces a to-and-fro motion of the traveller across the paper. A simple cam in the traveller brings the recording stylus into contact with the paper in the left-to-right direction and lifts it off on the return journey. A roll of unsized paper is wound slowly past a wick, which wets it with chemical solution, or with water if the paper has been previously impregnated with chemicals. It then passes over a bevelled bar where the record is made, and thence to a collecting spool. The instant of transmission of the sound impulse is synchronized with the zero position of the stylus as it begins its traverse across the paper; at this instant a stain is produced on the record. While the high-frequency sound impulse travels from the transmitter to the receiver via the sea-bed the recording stylus traverses the paper strip. At the instant of arrival of the echo a second stain is produced on the paper strip. This procedure, repeated at regular intervals, results in two stained bands on the record, the first of which represents the instant of transmission and the second the instant of arrival of the echo. The distance apart of these bands is proportional to the depth of water through which the high-frequency sound has travelled. The scale of depth indicated by the record depends, of course, on the speed of traverse of the stylus across the paper. For example, the width of the actual record in very shallow-water sets is approximately 5 in.

* Capt. A. J. L. Murray and N. Shuttleworth, British Patent No. 329403.

per 200 ft. of depth, since the stylus crosses the record in 1/12th sec. approximately. In a 200-fathom recorder the speed is one-sixth of this. A variable-speed drive might of course be incorporated to vary the speed of traverse of the stylus, so that the same paper width would correspond to any required range of depth to be recorded. Provision is made in some recorders for a total range of depth of 0 to 420 fathoms. The recording stylus crosses the paper in a time corresponding to 70 fathoms, and by advancing the instant of transmission in steps equivalent to 50 fathoms the series of overlapping ranges 0–70, 50–120, 100–170, . . . 350–420 fathoms, is obtained. This expedient increases the effective width of the record by 6 times.* In another experimental recorder the initial depth-range, determined by the width of paper, is 0 to 240 fathoms with provision for a zero advance of 200 fathoms, giving a maximum recordable depth of 440 fathoms.

An additional commutator has been introduced which causes the recording stylus to make a series of dots on the paper at equal intervals of depth—every 10 or 20 ft. in the very shallow-depth recorder and every 10 or 20 fathoms in the deeper-water sets. The dots form a series of equidistant lines on the record and provide a very convenient scale for reading the depth. As the depth scale is dependent for its accuracy on the speed of the stylus across the paper, it is important that this speed should be maintained constant. The driving motor is therefore provided with a reliable governor to control the speed within ½ per cent. A resonant steel-reed vibrator is mounted on the base of the recorder to indicate that the machine is running at the correct speed.

In some recorders designed specially for hydrographical surveying, provision is made for recording and numbering "fixes" to correlate the recorded depths with cross-bearings on shore marks. At the instant of making a fix, a line is produced on the record by momentarily short-circuiting the depth-marking commutator. Each line is subsequently identified by a serial number printed near the edge of the record (see, for example, Fig. 15 on Plate 3).

(7) Tests in Laboratory Tank.

To examine the behaviour of the assembled apparatus, the magnetostriction transmitter and receiver were

* J. G. Crace and F. L. Anthony, British Patent No. 370051/32.

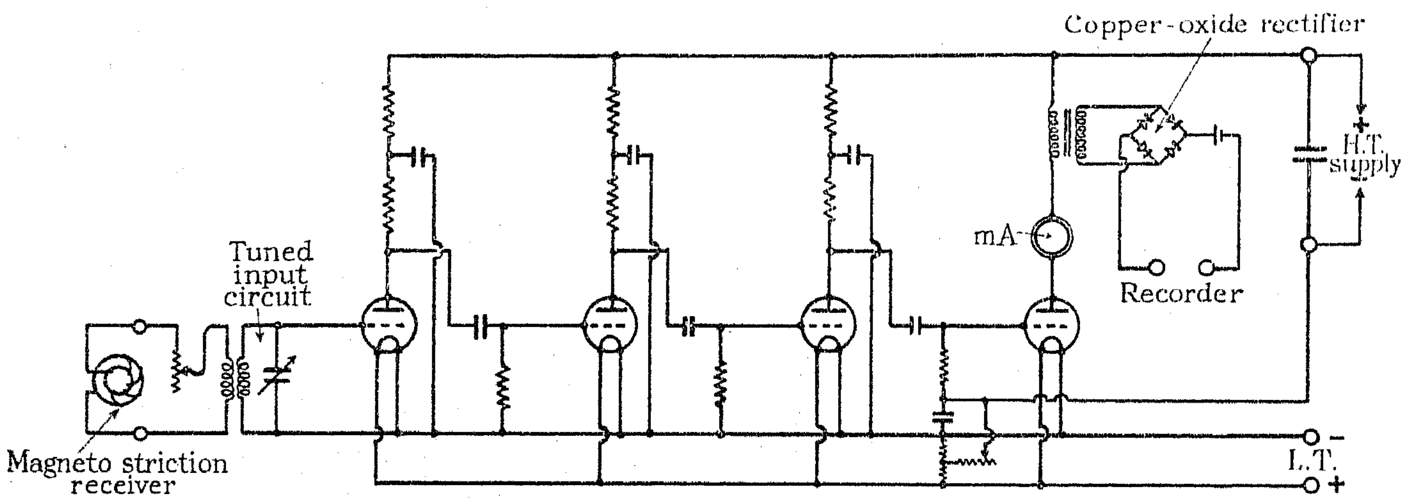


Fig. 13.—Resistance-capacitance-coupled amplifier.

mounted side by side with their axes horizontal at a depth of about 3 ft. in the laboratory tank. The tank is 15 ft. wide, 10 ft. deep, and 85 ft. long. Regarding the end of the tank as corresponding to the sea-bed, a range of depth of approximately 80 ft. is available. Actually, the total effective range of depth is much greater than this, for the low-speed recorders show a series of multiple echoes spaced 85 echo-feet apart.

Fig. 15 is a typical record showing the first and second echoes. It was obtained with the recorder for shallow water (range up to 200 ft.) with reduced sensitivity. The equivalent variation of depth was obtained by moving the transmitter and receiver along the tank on a travelling platform. The sharpness of the first recorded echo permits of an accuracy of $\pm$ 1 ft. in the estimation of depth. Fix or cross-bearing lines with their corresponding numbers are shown on this record. The overall sensitivity of magnetostriction depth-recorders was sometimes measured by counting the number of

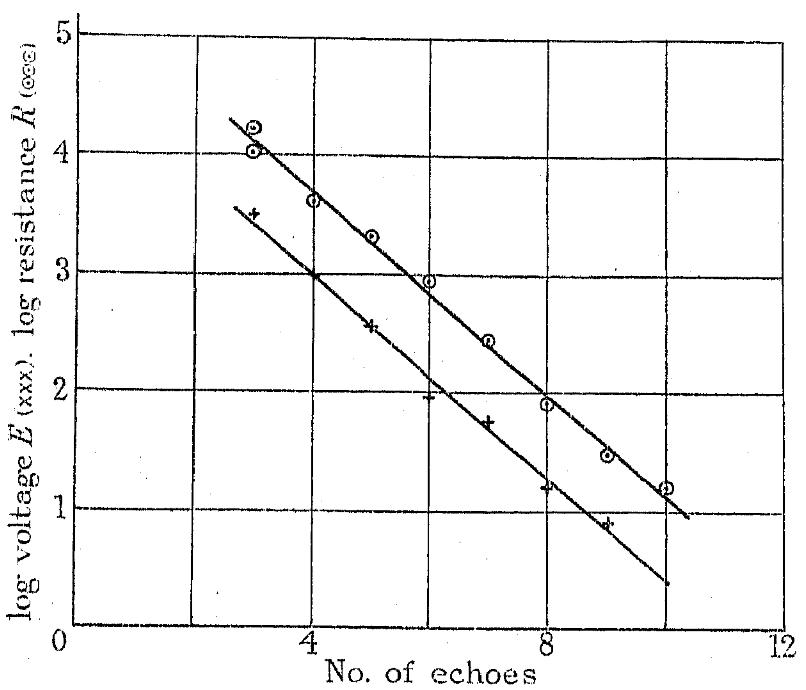


Fig. 16.

successive echoes which could be recorded. The relative strengths of successive echoes were measured in two ways, (*a*) by adding resistance R to the circuit of the receiver until any required echo was only just visible on the record, and (*b*) by measuring the electromotive force E developed in the receiver by means of the signal-strength meter described by B. S. Smith and F. D. Smith.* This instrument produces known alternating electromotive forces which can be matched on the record with the echo.

The results of such a series of measurements by methods (*a*) and (*b*) are plotted in Fig. 16, which shows clearly the regular logarithmic decrease of echo strength in a succession of 9 or 10 echoes in the A.R.L. tank. Both methods of observation indicate that the electromotive force, proportional to sound amplitude, produced by each echo is 2·6 times that of the one following. A gain of an additional echo therefore represents a very marked improvement.

The cathode-ray oscillograph† has been used extensively in making comparisons of magnetostriction transmitters and receivers. Reference has already been made to an investigation of the wave-form of transmitter current-impulse and received sound-impulse. The following problems, all bearing directly on the performance and efficiency of the apparatus, have also been examined with the help of the oscillograph.

(1) Variations of capacitance and voltage in the transmitter circuit,
(2) Modifications in the size and shape of reflectors,
(3) Variations of water-damping in transmitters and receivers,
(4) Transmission of sound through steel plates of various thicknesses,
(5) Variation of the distance between the magnetostriction oscillator and the steel plate (ship's hull),
(6) Directional properties of various reflectors and oscillators.

Such measurements with cathode-ray oscillograph and signal-strength meters have resulted in a considerable improvement in the apparatus. In the first experiments only one end reflection was recorded in the tank; it is now possible to obtain 11 or 12 successive echoes.

(8) Experiments at Sea.

Sheerness Experiments.

The apparatus in its original form was first tested in a survey motor-boat at Sheerness in February, 1930. Good records were at once obtained of the contour of the sea-bed with the motor boat running at full speed (8 knots) in choppy water. The depths available and actually recorded varied from 0 to 95 ft. and agreed well with soundings taken by lead line. In the latter case reliable measurements were possible only when the bottom was nearly flat and the boat was stopped. Specimens of early records are shown in Fig. 17 (Plate 3). The first record represents a run at 8 knots across the main channel from a shallow boat-camber on one side to mud flats on the other. In the second record, which crosses the channel at its deepest part (92 ft.), a second echo is recorded. This second echo is visible on the record at 200 ft., the maximum depth for which the recorder was designed. As a result of these experiments a number of modifications were made in the apparatus. In an earlier form of recorder the platinum recording stylus was driven by a chain passing over two sprocket wheels. This arrangement worked fairly well, but vibration of the chain and backlash in the links at these high speeds resulted in a certain amount of blurring of the record. It was replaced by a spiral drive (see Fig. 14) which runs very smoothly and gives a record relatively free from irregularities. In these early experiments the transmitter and receiver were fitted in a frame on the gunwale of the boat and held at a depth of 18 in. below the water-line. This temporary outboard mounting was replaced by a more permanent inboard arrangement. Two openings, 8 in. square, were cut in the bottom of the boat and wooden tanks constructed above them, the upper edge of these tanks being 6 in. above the water-line. This arrangement facilitated the removal of either the receiver or transmitter for inspection or adjustment without the necessity of docking the boat. A few runs

* See Reference (8).

† *Ibid.*, (9).

were made with the hull openings uncovered, but it was soon found that air bubbles and seaweed collected in the transmitter and receiver cones and ultimately cut off the sound completely. The holes were subsequently covered with copper sheet of the same thickness as that used to sheath the bottom of the boat. Good records were obtained at full speed even in bad weather. No trouble was experienced from extraneous noises, such as engine, propeller, or water noise, nor from the generator charging the 12-volt accumulators which supplied the whole system, including the amplifier, with power.

Frazerburgh Experiments—H.M.S. "Fitzroy."

Further tests of the depth recorder for shallow water (survey motor-boat type) were made in the Moray Firth, about 10 miles due north of Frazerburgh. The recorder was then tested in deeper water up to the limit of its range, viz. 200 ft. In these experiments the cylindrical scroll-type magnetostriction oscillators of frequency 16 000 cycles per sec. were used with the damped-impulse (condenser discharge) method of transmission A condenser of 8 μF capacitance was found to give the best results in the transmitter circuit. With a charging voltage of 250 this condenser supplied 0·25 joule per impulse, whilst at 400 volts the energy per impulse was increased to 0·64 joule. The records in the shallow-depth range 0 to 200 ft. were made with a recording speed of 4 ft. per sec. and a paper speed of 1 in. per min. approximately. Under these conditions good records were obtainable up to a depth of 120 ft. with a transmitting voltage of 150, and up to 180 or 200 ft. at 250 volts. Increase of transmitting voltage to 350 or 400 ensures greater reliability near the maximum depth. During these experiments the sea was rather lively; the waves were several feet high with "white horses," and the boat rolled and pitched considerably. In spite of this the bottom contour was clearly recorded up to the limit required, the echoes being quite strong at 30 fathoms. The record was not quite continuous: this was due to the violent motion of the boat and to masses of air bubbles which cut off the sound intermittently at both transmission and reception. A similar record with the echo depth gear arranged outboard from H.M. Survey Ship "Fitzroy" was almost entirely free from discontinuities. The improvement was undoubtedly due to the relative freedom from air bubbles and the greater steadiness of the larger vessel.

By reducing the recording speed to one-sixth, i.e. 8 in. per sec., the depth scale was converted from feet to fathoms. At this speed depths up to 120 fathoms, the maximum available near Frazerburgh, were clearly recorded.

Since that time improvements have been made by increasing the sound output and general efficiency of the apparatus to ascertain whether the depth recorder can be used, without serious modification, in greater depths.

Stornaway Experiments—H.M.S. "Flinders."

With this object in view a further series of tests were made in H.M. Survey Ship "Flinders" in water shelving from 16 fathoms, near Stornoway, to 1 000 fathoms, north-west of the Isle of Lewis. Ring-type magnetostriction oscillators, resonant at 15 kilocycles per sec. and fitted with 12-in. diameter reflectors, were mounted side by side in tanks welded to the hull of H.M. Survey Ship "Flinders." One of these tanks is shown in Fig. 18. The high-frequency sound impulse and the returning echo therefore pass through the water of this tank and the steel hull, which in H.M.S. "Flinders" is $\frac{3}{8}$ in. thick. Means were provided, as Fig. 18 shows, for varying the distance inside the tank between the magnetostriction oscillators and the hull. Experiments were also made with the same oscillators submerged to a depth of 10 ft. at the end of a strong pole lashed firmly to the side of the ship. A comparison of echo strengths obtained with the oscillators in this position and when mounted in the tanks, inside the ship, provides information relative to the loss of sensitivity due to the steel hull-plating.

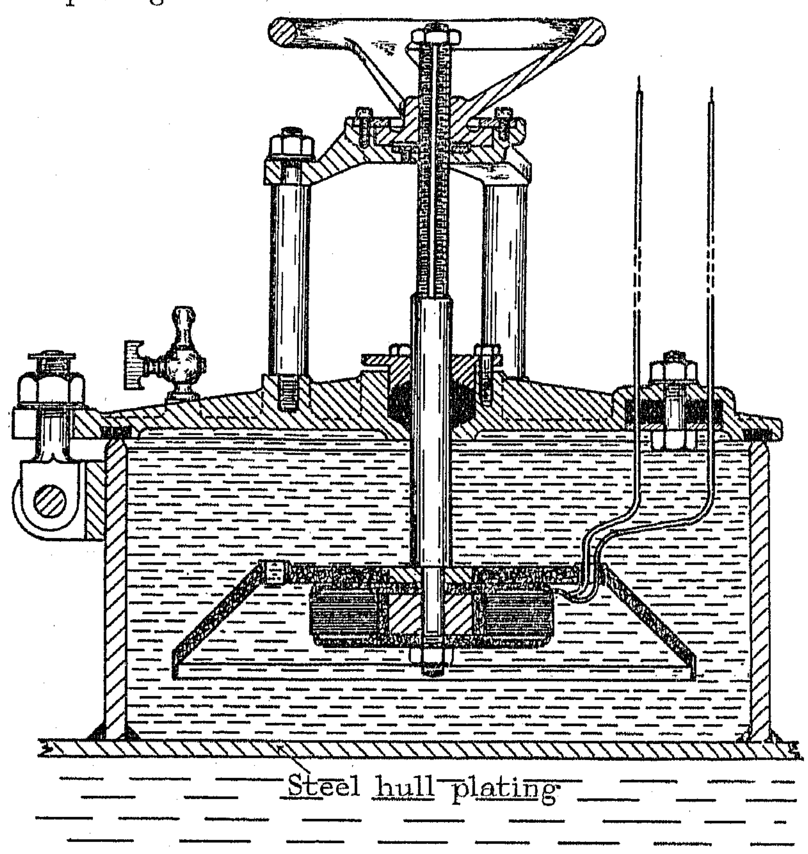


FIG. 18.—Magnetostriction oscillator (ring type) mounted in water-filled tank on hull of ship.

The recorder and circuit controls were mounted in the wheelhouse, whilst the electromagnetic transmitting key and condensers were in a watertight box attached to a bulkhead near the inboard magnetostriction oscillators. The cable connecting the latter to the condensers was thus reduced to 3 or 4 yards only.

In this series of experiments a comparison was also made between the "damped impulse" and "continuous-wave" methods of transmission.

A preliminary test of the apparatus was made during the journey of H.M.S. "Flinders" from Exmouth to Lochinver in May, 1932. Inboard oscillators excited by the "damped impulse" (condenser discharge) method were used, the ship proceeding at its normal cruising speed of 10 knots. A specimen record, made in the North Channel (Beaufort Dyke) between Stranraer and Larne, is shown in Fig. 19 (Plate 1). The greatest depth encountered (150 fathoms) is clearly recorded.

Trials of the apparatus in deeper water commenced on

the 20th June, 1932, when the recorder, equipped for recording ranges 0 to 240 and 200 to 440 fathoms, was started near Stornoway in a depth of 16 fathoms, continuing north-west of the Flannen Islands into 1 000 fathoms. The speed of the ship was normally 10 knots when inboard oscillators were used, but unavoidably reduced to 4 knots in the outboard tests on account of the risk of damage to cables. The weather was moderate during the tests, with a long swell and a somewhat choppy surface.

The records obtained, both "inboard" and "outboard," were good in depths up to the limit of the recorder, viz. 440 fathoms. Both the damped-impulse and the continuous-wave method gave good records at this depth. At the usual cruising speed of 10 knots no interference from ship or water noises was recorded. Specimen records are reproduced in Figs. 20 to 23 (Plates 2, 3, and 4).

Damped-Impulse Method (transmitting and receiving through the $\frac{3}{8}$-in. steel hull). (See Fig. 20.).—In the shallower water, up to 200 fathoms, the transmitting voltage applied to the condensers was 450, raised to 900 or 1 000 volts in deeper water. As the depth approached 240 fathoms, corresponding to the full width of the paper, the zero was advanced 200 fathoms. The upper edge of the record is thereby changed from 0 to 200 fathoms and the maximum recordable depth increased from 240 to 440 fathoms. This is shown clearly on the record. In this run the ship was pitching in a long swell and moderate sea, the angle of heel was about 6°, and the double amplitude of roll was from 0° to 12°. The bottom is clearly recorded up to 440 fathoms. The fainter parts of the record have suffered considerably owing to storage of the records and in reproduction. On the return course the record is first made on the 200- to 440-fathom range, subsequently reducing to the 0- to 200-fathom range.

The same pair of oscillators was mounted outboard at a depth of 10 ft. below water near the corresponding inboard position. As before, the maximum depth was recorded. Echo-strength measurements indicated that the first bottom echo was 2 to 3 times as strong as that obtained at the same depth when the magnetostriction oscillators were mounted in the tanks, the sound in the latter case traversing the $\frac{3}{8}$-in. steel hull twice. This indicates a loss of about 60 per cent in amplitude in the combined transmission and reception through the hull.

Continuous-wave Transmission.—The transmitter was magnetized by a direct current of 10 amperes. An alternating current of 4 amperes at a frequency of 15 kilocycles per sec. was momentarily superposed on the direct current at each transmission. The records indicate that the duration of each transmission, and the corresponding echo, is greater than in the damped-impulse method. In Fig. 21 the range 200 to 440 fathoms is recorded. Near the left-hand edge of the record at the point marked C a deep cleft in the sea-bed appears at 350 fathoms, the bottom of which is not recorded. At 440 fathoms, at the point marked W/T, a number of lines cross the record. These are due to electrical interference produced by a radio transmitter a few feet away from the amplifier in the receiving circuit of the echo depth-recorder. On the return course of the ship, from deep to shallow water, a break is shown in the record at the point marked S, where measurements were made of the strength of the echo at a depth of 310 fathoms. The record continues in Fig. 22. The echo is very strong at every transmission, even the second echo at 120–240 fathoms being clearly recorded.

Measurements of echo strength made during the progress of these records showed the possibility of recording at still greater depths, and comparison of inboard and outboard measurements again indicated a total loss of about 60 per cent in amplitude for transmission and reception through $\frac{3}{8}$-in. steel hull plating. This result confirmed previous observations of a similar character made in the laboratory tank at Teddington.

Messrs. Henry Hughes and Sons manufacture magnetostriction echo depth-recorders for the Admiralty and have also fitted them to a number of vessels of the trawler class. These vessels have usually $\frac{3}{8}$-in. steel hulls sloping at a considerable angle from the keel. The high-frequency sound is incident on the steel plating at an angle of about 12° as it leaves and re-enters the ship after reflection from the bottom. Nevertheless very satisfactory records have been obtained even in rough weather with this type of vessel at full speed. A specimen record obtained by the Grimsby trawler "Glen Kidston" off the Norwegian coast near Bergen has kindly been supplied by Mr. Hughes and is shown in Fig. 23. The manner in which this record reveals the rugged "alpine" character of the sub-marine scenery is very striking. The scale of this record is 70 fathoms in depth, and the time marks are made at intervals of 1 minute, the ship's speed being about 10 knots. The recorder on "Glen Kidston" is provided with an adjustment for advancing the instant of transmission in steps of 50 fathoms, and good records have been obtained up to 300 fathoms.

(9) Conclusions.

(*a*) *Requirements of Echo-sounding Apparatus. Ranges of Depth Sounding.*

The depth of the sea varies from 0 to 5 000 fathoms approximately, and the ideal depth recorder might be expected to cover the whole of this range with the same percentage accuracy at all depths.

The majority of ships, however, have little or no interest in deep-water (oceanic) soundings, but become more and more interested as the depth decreases. Ultimately, in very shallow water, a knowledge of the depth is of primary importance. A ship in very shallow or rapidly shoaling water, especially in insufficiently charted localities, must take frequent soundings. The importance of an echo depth-recorder therefore increases as the depth diminishes.

The depth range of the sea may conveniently be divided into three parts, (1) very shallow water, 0–30 fathoms, (2) water of medium depth, 30–200 fathoms, and (3) very deep (oceanic) water, 200–5 000 fathoms. Practically all ships which require soundings at all are concerned with the first of these ranges, 0–30 fathoms. Within this range the safety of the ship may be involved.

Of less, but still very great, importance is the range of navigational soundings extending up to 200 fathoms or so. Soundings in such depths are of value to the

navigator who may use the record as a means of checking the position of the ship. Relatively few ships have any interest in depths beyond this range, say up to 5 000 fathoms.

The magnetostriction echo depth-recorder which has been described fulfils the more important requirements. It measures the depth to about 1 ft. in water of any depth from zero to 30 fathoms or so, and in this respect is valuable to ships in dangerous or unknown shallow waters. This sensitiveness to depth in shallow water reveals in considerable detail the presence of wrecks or large rocks on the sea-bed. There are also important applications in survey work in rivers and harbour mouths, where the recorder may be used to control dredging operations and to check the thoroughness with which such operations are carried out. As regards navigation, experience has shown that the magnetostriction apparatus can give a good record of depth up to 400 fathoms or more, even when the sound is transmitted and received through a steel hull $\frac{3}{8}$ in. thick. The records were not appreciably affected by the noises made by the machinery and motion of the ship at the cruising speed of the vessels fitted. Good results were obtained in bad weather conditions, the rolling and pitching of the ship having but little effect on the record.

(*b*) *Choice of Position of Echo-sounding Apparatus in Ships* (*Vessels of shallow draught*).

This depth recorder has an important advantage over certain types in the actual fitting in ships. In low-frequency systems it is necessary to choose two positions in the ship separated by about 50 ft., so that the direct sound from the transmitter is prevented by the hull from reaching the receiver. The position of the receiver is further restricted because of excessive parasitic noises such as noises from the engine room, pumps and auxiliary machinery, water noises, and so on. These two conditions are sometimes difficult to fulfil. With the high-frequency magnetostriction system, however, the transmitter and receiver require no special screening. They may be mounted side by side, with no part of the hull separating them. The system is tuned both electrically and mechanically to a high frequency above the ordinary range of frequencies of the disturbing background of noise. Consequently the two main difficulties encountered in the low-frequency system do not arise. Whereas two positions in the ship must be chosen for the low-frequency type, only one is required for the high-frequency system. Furthermore, there is much greater freedom in the choice of the one position on account of the insensitiveness of the magnetostriction receiver to low-frequency noises. The importance of these considerations will be appreciated when it is realized that an error of judgment in the choice of positions of the transmitter and receiver in a ship may lead to complete failure.

When the draught of the ship is great the hull provides sufficient screening for the low-frequency system if the separation is of the order of 50 ft. or more. In ships of very shallow draught, however, it becomes difficult to provide efficient screening and the gear does not discriminate between the echo and the direct sound in shallow water. As already stated, the high-frequency gear requires no hull screening and in this respect should behave well in all types of craft. This property of the high-frequency system is a great asset.

(*c*) *Simplicity and Reliability.*

These two factors are of paramount importance in any gear which has to be used under average ship conditions. They become all the more important if the safe navigation of the ship depends on the depth recorder. Although the magnetostriction depth gear has been in use for a relatively short time only, it is possible already to form an estimate of its reliability and to correct some minor faults in its design. The most vulnerable element of any echo sounding gear is the part which is mounted in the water-filled tanks on the hull. These tanks are sometimes wellnigh inaccessible, and a defect in either the transmitter or the receiver is therefore liable to cause inconvenience and expense. In the magnetostriction system, both the transmitter and the receiver function even if flooded with water, so that the maintenance of watertightness is not vital. Provided insulation of good quality is used on the few turns (10 or 12) of wire which constitute the winding of the oscillator, no further attention should subsequently be required during the normal life of the cables. This feature is very important in gear which may be fitted in an almost inaccessible position in the ship.

(*d*) *Directional Properties.*

The magnetostriction system may have any degree of "directionality" required. Hitherto it has been found satisfactory to use a conical beam of sound of semi-apical angle 20° or 30°. The comparative ease with which the receiver can be screened from the transmitter is due to the relatively short wavelength (about 4 in.) of the sound, and the directional properties of the conical reflectors.

Another advantage of the directional characteristic is that the soundings are taken directly, or almost directly, beneath the ship; little or no sound is transmitted sideways and the receiver is therefore insensitive to echoes from submerged cliffs or banks. In this respect also the directional beam is more discriminative of detail than non-directional types and is less liable to miss a submerged rock or a wreck. It has been urged against the directional system that it is affected by the roll of the ship and by steeply sloping banks. Whilst it is true that some echoes may be missed under such conditions, the case is not so bad as it first appears. It must be remembered that the sea-bed is not a mirror, and that sound of short wavelength is returned to the receiver from directions other than the simple reflecting angle. The trawler record shown in Fig. 23 is a sufficient answer. Under the worst conditions of rolling, however, the record of the bottom contour would appear as a dotted instead of a continuous line.

ACKNOWLEDGMENTS.

The authors are glad to have this opportunity of expressing their appreciation of the generous help and support which have been accorded by the Hydrographic Department, and especially by Vice-Admiral Sir H. P. Douglas, K.C.B., C.M.G., and by the Commanding

Officers of H.M. Survey Ships "Fitzroy" and "Flinders."

Their thanks are also due to various other members of the staff of the Scientific Research and Experimental Department. They wish particularly to acknowledge their indebtedness to Dr. E. P. Harrison, F.R.S.E., F.Inst.P., who brought his early experiments on magnetostriction to their attention and emphasized the possibilities of the principle at a time when its importance was not generally realized, and to Mr. N. Shuttleworth, M.Sc., who devised the electrochemical method which has been used in the recorder.

The authors have also to thank the Admiralty for permission to publish this paper.

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DISCUSSION BEFORE THE WIRELESS SECTION, 2ND JANUARY, 1935.

Commander J. A. Slee: I should like to explain that I am speaking not as an individual but rather as the mouthpiece of all those who have been connected with the Langevin high-frequency apparatus. This now has some 10 years' experience of all kinds behind it; we have about 1 000 sets on English ships, about 400 on foreign merchant ships, and a large number in men-of-war. I have been able to draw on reports of its working not only from my colleagues in the Marconi Sounding Device Co. but also from the technical staffs of almost all the maritime nations of Europe. It is their knowledge on which I base my remarks, not my own. In particular, I am grateful to Mr. Florisson, of the French parent company, who was responsible for the scientific development of the apparatus in the early days.

The first mention of the use of magnetostriction for the purpose of converting electrical energy into oscillating energy was made by Garrett and Young in 1908, and 20 years later Pearce did a very great deal of work on the subject. With regard to the actual text of the paper, the opening words of the Introduction seem to suggest that the echo-sounding devices at present in use give only isolated soundings. That, of course, is not really so. In the early days there were two echo-sounding methods of which that could be said; one obtained its transmission by the firing of a bullet at the sea, and the other depended on a hand-operated clapper at the bottom of the ship, worked by pulling a string. Apart from those, however, I have not heard of any sounding device which did not provide a rapid and steady sequence of soundings for as long as it was switched on. Nearly all the types of apparatus now in service can be worked with a recorder, which will give a perfectly satisfactory and steady record of the depth. The authors omit to mention the "Fathometer" apparatus, which has been selected for use in the "Queen Mary." At the top of page 550, col. 2, it is stated that the new system of echo-sounding was devised to meet a definite requirement which could not have been met in 1929. I think it is right, therefore, to place on record that by that date high-frequency sounding was perfectly well established, and there were many types of recorders in use. The Marti recorder is dated 1922, while Langevin proposed photographic recording in 1923 and electrolytic recording in 1924.

So much for the historical side of the subject. I now come to the astonishing degree of accuracy claimed for the authors' method. I should like to know what has been done to eliminate from the electrolytic recorder so many of the minor and elusive sources of error which have given so much trouble in the past. I should like to ask the authors what is meant by their figure of 1 ft. for the degree of accuracy in a depth range of 0–200 ft. From Fig. 1 it would appear that the transmitter and receiver are mounted about 18 in. above the keel-line of the boat. When taking soundings one assumes as the datum the level of the emitter and receiver; presumably these are at the same height, and in soundings of less than 2 ft. the boat would not be afloat. Referring again to difficulties with the recorder, the zero or datum line—the "emission line," we will call it—must have some finite thickness. The emission consists of a number of cycles, and the stylus, having made a mark in the electrolytic colouring matter, is likely to drag on a little and thicken the emission line more than should be the case. Taking Fig. 17, for instance, on the right-hand side there is a very shallow sounding, but the emission line seems to be about 4 ft. deep; then there is about 1 ft. clear, and next we have a sounding which is 5 ft. below datum. What is the real minimum working depth below datum obtainable under seagoing conditions? Reverting to the question of the extraordinary accuracy of recording, how is the dampness of the paper controlled in various degrees of humidity and temperature? If the paper is ever so little too damp, the colouring matter deposited by electrolysis will spread and make a little blot. On the scale we are talking of here, a depth of 1 ft. of water is equivalent to a mark on the paper of $\frac{1}{40}$ in., and our experience is that if the paper is fairly wet there may be a comparatively large blot. Another point is that the amount of colouring matter deposited depends on

the current flowing through the stylus, and if an unusually strong echo comes along it puts down a bigger spot of colouring matter than a weak one. Is there any automatic limiting device which will cover the great variations due to changes in the coefficient of reflection of the sea bed, and the possibility of passing over disturbed or slightly aerated water? The point is not fantastic, because one often notices changes in apparent signal strength as great as 10 to 1. This question of blotting is more important than it may seem to be at first sight, because we have often found it to be a slow growth. At first the record may show a very narrow clear space, indicating a very shallow depth, but if one looks at the record a quarter of an hour afterwards one finds that it has blotted across. I am very anxious to know what has been done to get over those little troubles, which seem to be peculiar to electrolytic recording. Is any arrangement made on this high-accuracy recorder for obtaining automatically what surveyors call "slope correction?" Is there any arrangement for applying the corrections called for by the salinity or temperature of the water? These factors may well give errors far above the 1 ft. mentioned by the authors, particularly in deeper water.

I should like to refer to the false or compound echoes due to very heavy weeds or mud. With the rather thick echo-line which seems essential in this method of recording it seems to me that one may get an indication of the mud and not of the rock; it would not be possible to get them both. We are told in the paper—this is a point which is common to all recorders—that the governor controls the speed within $\frac{1}{2}$ per cent. With a reciprocating stylus and a reciprocating contact, which will put a varying load on the motor, I think that is an extraordinarily fine performance; but that $\frac{1}{2}$ per cent does not leave very much for the summation of all the other little errors if the high overall accuracy mentioned by the authors is to be obtained.

With regard to the magnetostriction effect, Fig. 10 indicates that there must be a most astonishing series of physical events between the moment when the transmitting contacts close and that when the rings cease to vibrate. Oscillogram (A) (1) shows that the period of the first kick is about one whole cycle of the rings, which then have a moment's pause and then get another kick the other way. The series of changes must be dreadful. When does cavitation set in? The only published figures of which I am aware are those given by Dr. Aigner in Germany in 1922. We get about the same figure, and if it is a correct one the maximum pressure one can get into water at any depth such as we are likely to work at is only 14 lb. per sq. in. Hence this terrific discharge must give rise first to cavitation and then to magnetostrictive saturation before the rings settle down to vibrate regularly. The effect is very complicated, and I should like to know something more about it. Fig. 10(B)(2) represents, I suppose, the working condition of reception, and the most astonishing thing about it to my mind is the extraordinarily slow growth of current in the receiver. If this applies to the 0–200 ft. high-accuracy survey work, it seems to me that this very slow growth, coupled with the vagaries of reflection and absorption, might easily introduce errors of ± 1 ft., because at these frequencies there are only 3 cycles to the foot.

I should like to know the power required for these various sets, and the maximum and minimum depths which each of them is capable of recording. Can these minima and maxima be obtained from the same set, and is it possible to change over from damped to continuous-wave operation?

Fig. 18 shows a ring-type oscillator mounted in a water-filled tank; with a mounting of that sort there would be a chance of reverberations in the tank, which would have the effect of stretching out the emission line. Some of the emission lines shown in the paper are very wide indeed; many of them are 10 fathoms, and one is 30 fathoms, in width. The paper does not tell us how the width of that emission line for work in moderately shallow water is adjusted. On the question of sounding through the hull, the arrangement shown in Fig. 18 was used for sounding through a $\frac{3}{8}$-in. plate at 400 fathoms with the ship moving at 10 knots; the relevant record, Fig. 20, shows that there was not very much left in hand. Can the authors give us some data which will connect together the thickness of the plate, the losses incurred in penetrating it, the reverberation effect, and, above all, how the figures must be modified if the skin of the ship is not parallel to the face of the reflector? It looks as if there might be some limiting angle where the reflection from the skin would become so great that the skin would be, practically speaking, impenetrable.

All the authors' records were taken at extremely low speeds. They make no reference to ships of light draught, to ships trimmed light fore and deep aft, or to higher speeds. Can the authors give us any data which will prove or disprove a reduction of range progressively with speed? The conditions of light draught and uneven trim are the difficult ones from the point of view of the people who have to take the soundings. The conditions under which the authors' records were taken are all so easy that they lose half their practical importance. I should be glad if they could tell us something about the connection between speed, trim, the slope of the ship's bottom, and the thickness of the skin plates.

Mr. C. S. Wright: I should like to express my sympathy with the authors if they are expected to reply to Commander Slee's questions on practical sounding!

The paper describes the investigations leading to the construction of the first experimental instrument, the details of its construction, and the preliminary sea trials, the latest of which took place in June 1932.

Mr. A. J. Hughes: The progress which the art of sounding has made in this country is remarkable. In 1926 the first echo-sounder ever fitted in this country —one of the British Admiralty sonic sounders—was installed in the Royal Mail liner "Asturias." Since that time 1 500 to 2 000 echo-sounders have been fitted in all classes of ships in this country, a fact which speaks very highly for the foresight and efficiency of the shipowners.

I think the sonic gear served a very valuable purpose, but in my opinion the advent of magnetostriction opens up another field altogether for echo-sounding, and it points to the introduction of the supersonic oscillator

as the right basis for echo-sounding. There are two or three reasons for this. One is the extreme lightness and compactness of the oscillator, and the fact that it is non-mechanical. There is another feature of the magnetostriction oscillator, however, which puts it far beyond any other oscillator of which I know, and that is the great energy which can be developed with magnetostriction.

Answering at any rate one of Commander Slee's questions, it has been easily possible to get depths of 2 000 fathoms when working through ⅜-in. plate, and, further, to get continuous soundings at 1 000 fathoms in a modern motor-ship travelling at 18 knots, working through a ⅝-in. plate. In the latter case, both transmitter and receiver were working through the skin of the ship, which was not cut out in any way.

The magnetostriction echo-sounder has valuable properties for survey work in shallow water. Commander Slee asked the smallest depth which it is possible to measure below the bottom of a boat; it is safe to say that by means of the authors' apparatus one can measure to 3 in. below the bottom of a ship.

Captain J. F. Hutchings: The practical result of the machine described is one which is acceptable to seamen both from a surveying point of view, where very great accuracy is necessary, and also from a seagoing point of view, where perhaps such absolute accuracy is not necessary but where reliability is essential.

I hear that the Mersey Docks and Harbour Board are very pleased with the boat gear, and they would not be pleased with it if it were not accurate. They are content to do away with the leadsman because they realize that the echo-sounder can do a great deal more than ever the leadsman could. By using it they can get through six times as much work in a day, and have learnt in a few weeks far more about the details of the bottom of their channel than they ever dreamed of before. While I was in Liverpool they actually discovered a shelf on the bottom which they had previously been quite certain did not exist. It was checked over again by the echo-sounder and confirmed, and then very accurately and carefully hand-leaded. The shelf proved to be there, and, what is more, it proved to be as given by the echo-sounder to within a few inches.

Quite recently when going down the Clyde in a ship of very light draught at 16 knots, we recorded a shoal not shown on the chart. By a coincidence I have in my possession a chart taken by another ship altogether, when I was not present, on another occasion and under different conditions, but on the same track, recording the same shoal. That shoal will in due course be reported to the Admiralty, and doubtless will be investigated by them. There is no doubt about its existence.

Mr. R. W. Minter: There is a dreadful antipathy at sea, especially in the mercantile marine, to the use of anything but the sextant and the hand lead; and the device which has been described by the authors will deserve a great deal of praise if it succeeds in breaking down the idea that nothing but a sextant in a hazy sea, and a hand lead coming up Channel in dense fog, will tell the seaman where he is. The difficulty of persuading navigators that even the direction-finder is more accurate than the bell they think they can hear on the land in one direction when it is really coming from the other, is surprising, and my own experience shows that their antipathy even extends to faking the results to prove that the electrical apparatus was wrong. In one case my previous acquaintance with the Navy (though I was in the mercantile marine at the time) led me to discover that there was a novel way of plotting direction-finder bearings on the chart to find the position, the protractor being put at 88° instead of 90°! If the magnetostriction echo-sounder encounters similar troubles the authors should not worry very much.

Mr. L. S. Harley: Can the authors give me any idea of the e.m.f. generated in the receiving magnetostriction apparatus with normal echoes from, say, 10 fathoms?

Secondly, I understand that they use the same windings on the receiver as on the transmitter. That is rather surprising; I should have thought that a larger number of turns on the receiver would have avoided loss of sensitivity due to a high-ratio transformer between receiver and amplifier.

Mr. W. Lucas (*communicated*): It was remarked by one of the authors, when introducing the paper, that their depth recorder is the first application which has been made of the long-known magnetostriction effect. The application of magnetostriction to the reception—though not to the generation—of submarine sounds, together with the increase of the effect obtained by tuning the nickel rod to resonance with the sound to be received, was however, first described in 1908 by T. A. Garrett and W. Lucas.* In an actual trial of their invention at the mouth of the Mersey, the greatest distance at which the submarine bell of the North-West Lightship could be heard was about 2 miles. The test showed that this magnetostriction receiver was much less sensitive than the carbon-button microphones then used for the reception of submarine-bell sounds, and consequently, in spite of its advantages in other respects, it was abandoned. This was before the time of valve amplification such as is used by the authors. Had this been available then, the small sensitivity would have been of little consequence.

Dr. A. B. Wood, Dr. F. D. Smith, and **Mr. J. A. McGeachy** (*in reply*): Commander Slee does not appreciate (1) that the paper is not intended to include a complete history of echo depth-sounding and (2) that the information given in the paper relates to the first experimental apparatus and to the preliminary sea trials; subsequently, it is understood, there has been considerable development for commercial purposes.

On the historical side, it might be appropriate to draw Commander Slee's attention to his own paper before the Institution on "Reflection Methods of Measuring the Depth of the Sea."† In the course of an introductory survey he remarked that "The author has not been able to find any record of anything having been achieved on a sea-going scale until the War period." Yet he now refers us to literature dated 1908. We are fully aware of Garratt and Young and Pierce's papers (and of Joule's work in 1841) on magnetostriction, but in none of these is an efficient practical construction described. The statement, which Commander Slee questions, at the top of the second column on page 550 of our paper, viz.

* British Patent No. 21727—1908. † *Journal I.E.E.*, 1931, vol. 70, p. 269.

that the new system was devised to meet a definite requirement which could not be met in 1929 by any system then in existence, is, we believe, correct. We were asked in 1929 to record the depth of very shallow water from a motor boat with what Commander Slee *now* (1935) regards as "the astonishing degree of accuracy" of 1 ft. in a depth range of 0–200 ft. As regards the minimum depth recordable—the apparatus was capable of recording down to a depth of less than 1 ft.—the fact that the motor boat used in the course of other tests had a draught of $1\frac{1}{2}$ ft. is a property of the boat, not of the depth-recorder! It should be obvious that what is actually measured is the time of passage of the sound wave from the transmitter to the sea bottom and back to the receiver, and that this result is subject to modification in accordance with the nature of the information desired—suitable instrumental adjustments being made to allow for draught of ship, position of oscillators, velocity of sound, etc.

With regard to the accuracy, the difficulties to which Commander Slee refers have, it is believed, all been surmounted. (1) The record did not "blot" as he implies, proper solutions and means of applying them to the paper having been employed. (2) The governor controlled the speed, as stated, well within $\frac{1}{2}$ per cent, the power required to reciprocate the recording stylus being a very small fraction of the total power available.

We agree with Commander Slee that the magnetostriction phenomena associated with the condenser discharge, illustrated in Fig. 10, are very complex, but the fact remains that this method of emitting the high-frequency mechanical oscillations has the outstanding virtues of success and simplicity. We had no evidence of cavitation—perhaps it does not occur so readily with sound impulses of very short duration. The rate of rise of current in the receiver circuit, as shown in Fig. 10B(2), is determined by the tuned input circuit—in shallow water, up to 30 fathoms or so, the echo is very strong and the record commences after 1 or 2 oscillations only, so that the time-lag introduced owing to this cause is very small and does not vary over such a small range of depth. In the limiting case, for the maximum depth recordable, the time-lag may reach 0·001 sec., corresponding to a depth of $2\frac{1}{2}$ ft.; in depths of several hundred fathoms this is negligible. If, however, the need for very high accuracy arises in exceptional circumstances, a more rapid rise of current in the receiver circuit may be secured by the use of an untuned input circuit.

The experimental motor-boat depth-recorder illustrated in Fig. 14 takes 5 amperes at 12 volts and was designed to cover a depth range of 0–200 ft. The minimum depth in practice is, as stated above, limited only by the draught of the boat. The maximum depth recordable by the magnetostriction method has not yet been ascertained, but we understand that Messrs. Henry Hughes have made sets which have recorded 2 000 fathoms through a $\frac{3}{8}$-in. steel hull.

The water-filled tank shown in Fig. 18 probably had the effect of increasing the duration of the sound transmission, but this introduced no difficulty. As regards the width of the emission line, in shallow water sensitivity control was introduced, which eventually suppressed the initial (transmission) record [see page 551, col. 2, and Fig. 17(*a*), Plate 3]. This suppression of the initial signal was hand-operated but might have been done automatically.

The remaining questions raised by Commander Slee do not fall within the scope of the paper, which, as already explained, deals with the first experimental instruments and preliminary sea trials.

In reply to Mr. Harley, the voltage developed in the receiver circuit at the input of the amplifier may be deduced from the oscillograph record Fig. 10B(2), which indicates the echo at $2\frac{1}{2}$ fathoms. The amplification of the tuned circuit in this case was about 80 and the sensitivity of the oscillograph about 1 mm per volt—the reproduction is actual size.

It is undesirable to wind the receiver with a large number of turns of fine wire on account of the shunting effect of the capacitance of a long cable on a high-impedance winding.

The account given by Mr. Lucas of his early experiments is very interesting. It was unfortunate for him that valve amplification was not available in 1908.

DISCUSSION ON

"GENERATION, DISTRIBUTION, AND USE, OF ELECTRICITY ON BOARD SHIP."*

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE,† AT LIVERPOOL, 21ST JANUARY, 1935.

Mr. S. B. Freeman: The paper which has been put before us is very timely. A great many shipowners are now wishing the time had come when they could build again, and are considering what they would build, supposing that good time had arrived. It is quite clear that electrical transmission of power at sea has come to stay and is one of the alternatives to be taken into account when new ships are being built. Whether the industry will have such a boom year as 1931 for some time is doubtful. The four ships mentioned in Table 1 were all built in 1931, and it is to be hoped for the benefit of the electrical industry that future years may produce a similar crop of electrically-operated ships. There is no doubt that passengers like the electrically-propelled ship, chiefly because it is clean. A combination of steam, oil engine, and electric motor, however, is very probably the right solution.

The items which have to be considered for every fresh building problem are: (1) reliability, (2) ease and certainty in handling, (3) weight and space available, (4) capital cost, (5) fuel and maintenance costs, (6) power for auxiliary machinery as a percentage of main power. The reliability and the handling requirements of electric transmission plant are proved as of equal value at least with those of other accepted systems. As regards the claim that electric propulsion enables the vessel to manœuvre at full speed astern, the extra load which would be thrown upon the steering gear in many cases would make the construction and weight of the rudder and its gear undesirably heavy, and in many cases impossible. The weight and space necessary in comparison with the turbine may be about the same, although this would not be agreed to by protagonists of mechanical gearing. For oil-engine proposals the factor of bunker weight comes in, giving a ratio of 0·4 to 0·75 in the amount of oil to be carried in bunkers. With regard to the capital cost, we have recently been making inquiries from builders and we find that the relative costs for various types of propelling machinery of 8 000 s.h.p. are as follows, steam reciprocating propelling machinery with Scotch boilers working at 220 lb. per sq. in. being taken as unity: mechanically-geared turbines with water-tube boilers at 400 lb. per sq. in. working pressure, 1·25; turbo-electric with water-tube boilers at 400 lb. per sq. in. working pressure, 1·44; oil-engine electric, 1·81. So far as can be learnt, the fuel consumptions of the engines for those vessels enumerated in Table 1 range between 0·725 and 0·78 lb. of oil per s.h.p.-hour. These figures do not compare favourably with the 0·57 to 0·6 lb. per s.h.p.-hour claimed for the mechanically-geared "Empress of Britain." There is one point on which a definite figure is desired, and that is the percentage loss of power through electric transmission. The figures given by different authorities vary widely, but probably 8 to 15 per cent would cover the loss.

None of the various types of prime movers are completely satisfactory for use with electric generating plant. The reciprocating steam engine has an uneven turning moment, the turbine unfortunately must work at high vacuum to be economical, and the oil engine has an uneven turning moment and needs either compressed air or electric batteries for starting; but a combination of these three—steam, oil, and electric engines—may provide a very efficient lay-out.

The auxiliary machinery is another very considerable point, and with the rapid growth of refrigeration it is going to be still more important. I should like to bear testimony to the value of electrical plant in refrigerating work. Two of our ships coming home from Australia carrying chilled meat with 0·5 deg. F. range of temperature, produce charts showing a straight line for those temperatures, but the electrically-operated plant is the easier to control.

The principal enemies of electric propulsion are evidently corrosion, damp, vibration, and carelessness in handling. The question of fire risk should be dealt with, to reassure the shipowner: electric cables should be non-inflammable. While we are much impressed by the care that has been taken in building the large motors described by the authors, and the precautions adopted against total breakdown, we know that at sea the unexpected often happens and that no class of machinery is eventually immune from trouble. If a small accident happens to the main motor, involving its repair and possible removal from the ship, is this a more serious matter than the failure, say, of a cylinder or cylinders or a gear wheel or pinion in mechanical plant? When an armature burns out in service every coil, as a rule, is burnt out; whereas if a row of blades or a single cylinder or one pinion or wheel fails, the rest can carry on.

The decision as to whether electric transmission or some other drive is adopted will, however, be decided in every case by the conditions of service, the draught of ship, the diameter and speed of the propellers, the hotel service required, the percentage of auxiliary power in relation to propelling power, and so on. That is where the value of an all-round training for the engineer responsible for the decision comes in. All our marine engineers have some knowledge of electricity, and this is required at the examinations for the Board of Trade Certificates. Our electricians are generally able to do some fitting and turning.

I am very much interested in the authors' remarks about the Board of Trade holding examinations and awarding certificates of competency to electrical engineers in marine work. When I made that suggestion in 1927 the Board of Trade toyed with it, but they did nothing. We get very well-trained electrical engineers going to

* Paper by Messrs. C. W. SAUNDERS, H. W. WILSON, and R. G. JAKEMAN (see page 241).
† Joint meeting with the Liverpool Engineering Society.

sea, but eventually they find there is no future for them. They cannot rise to the position of chief engineer—the outlook is not very attractive, and they leave us. We want to get men who have had a good electrical training superimposed upon a sound mechanical training, and there is no reason why such an engineer should not be in charge of a very big ship.

Mr. J. E. Allan: Reference is made in the paper to the necessity for maintaining in a clean condition all electrical apparatus, including dynamos and motors. This, in my opinion, is one of the very essential features necessary to produce satisfactory results and trouble-free running of electrical plants. It is noted in the paper, however, that except in a few instances such as deck machinery, forced-draught fans, etc., enclosed-ventilation drip-proof machines have been proved to give satisfactory results. The use of this type, particularly where ventilation fans have been fitted on the armature shaft, is intended, of course, to reduce the amount of copper in the machine. Such fans in the course of operation undoubtedly cause a concentration of foreign matter to be deposited in the air ducts and other crevices through which the air has to pass, with the consequence that in time the ventilation system becomes ineffective, resulting in increased heating of the windings with varying degrees of failure. Perhaps the authors may have some suggestions as to how to overcome this difficulty.

Referring to the use of roller or ball bearings in preference to sleeve bearings, this has been a controversial point amongst marine engineers for a considerable time, and experience has shown that while the ball and roller bearings have to be used in certain cases, the sleeve bearing is to be preferred from the maintenance point of view. The average sleeve bearing can be repaired by the ship's personnel, whereas in the case of the roller or ball bearings there are occasions when, notwithstanding the fact that requisite spares are carried, such repairs cannot be effected. For example, take the case of a ball bearing having by some unfortunate means jammed the races and caused the shaft to rotate in the inner race or, on the other hand, the outer race to rotate in the housing; such a condition presents the difficulty that when the replacement bearing is supplied either the shaft is too small or the housing is too large. In the case of the shaft being too small there is very little hope of either sleeving, or building up to the desired diameter by welding process, on board ship. Perhaps the authors would be good enough to explain how to overcome this difficulty. This, in fact, is a fairly common experience in connection with the use of ball bearings.

The isolating of non-essential circuits on large liners is undoubtedly a feature which commends itself, but it is doubtful whether any engineer in charge of such plant would be prepared to run his machinery on the understanding that should an overload occur automatic devices should rectify and balance the output from the machines. Such precautions have a definite advantage in isolating the dynamo whose engine has, for some unforeseen reason, failed to maintain its full rated horse-power, as sometimes happens, particularly with Diesel engines.

Regarding the control of winches, windlasses, and capstans, any form of control which gives the flexibility of a number of intermediate speeds and still maintains a reasonable torque at any speed, is more closely approaching the very suitable range of speed controls which the steam engine provides when used for driving winches, windlasses, capstans, etc. The electrical engineer has attained considerable success in endeavouring to produce the conditions which the steam engine offers.

Referring to centralized control, it is agreed that this form of control for engine-room motors offers many advantages over the unit system, and I thoroughly agree with the authors' remarks in this connection.

I should like to make a reference to the cables fitted on board ship. Unfortunately the authors are rather scanty in their remarks on this very important subject. If it is implied that the cables suggested by the authors are to form a link between the generating plant and the services for a period of 25 years, I fear that experience does not warrant such a claim. In fact, if the authors halved that period they would be coming more into line with the useful service given by the present-day electric cable. I concur with the authors that every care and consideration should be given to cable runs on board ship. This feature, unfortunately, is sometimes overlooked. The old, but very true, saying is: "If the cables could be installed as they are wound on the drums, very much longer life could be obtained."

Mr. A. C. Livesey: Liverpool is the birthplace of the use of electricity on board ship, at any rate in the merchant service, because I think it was one of the Peninsula and Oriental Steam Navigation Co.'s vessels which sailed from Liverpool about 60 years ago, fitted with one small dynamo which supplied light for one lamp in the saloon. At the other end of the scale we have the "Normandie" with a total generator capacity of 150 000 kW. These figures show the remarkable advance in the use of electricity on board ship.

Unfortunately—and here I should like to support what the authors have said—the status of the seagoing electrical engineer has not made strides commensurate with the use of electricity. This is a matter of vital interest to those of us who are members of the Institution. Mr. Freeman mentioned that he approached the Board of Trade some years ago; I should like to put forward the suggestion that the Institution, which is influential, might approach the Board of Trade with a view to co-operating with that body in establishing a better status for electrical engineers at sea. The disabilities under which such engineers labour will militate against obtaining and retaining the properly qualified men.

On page 244, halfway down the first column, the authors dismiss rather summarily the use of alternating current. It would be of interest to know why they do not think the a.c. commutator motor can be put to practical use on board ship. Many people think that the commutator motor is a practical solution, or that it will soon be a practical solution, of the problem of variable speed, as opposed to the method of regulating by valves. There seems to be a general opinion that one reason why direct current has held its own for so long has been the fact that a variable speed is so often required. It would be interesting to know whether the authors consider that there are other reasons why alternating current has not

yet made advances on board ship. In a recent paper* claims were made for it which, superficially at least, appeared sound. Have such apparently trivial details, for instance, as the initial "kick" current of a straight-on starter anything to do with the matter; or perhaps the hum from an a.c. magnet, which may be transmitted through the structure of the ship? If so, those may be deterrents, but I hardly think so, as there are a number of ships in service in which, while direct current is used for the engine room and deck machinery, alternating current is employed for kitchen and other services.

Coming to "Auxiliary Supply" on the same page, the authors mention 110-volt and 220-volt d.c. systems, but they do not refer either to double-pole or to single-pole systems. I should be rather interested to know their views on this matter, because at an informal international conference which I attended at The Hague last year it was very fully discussed. The German delegate's views strongly favoured the single-pole system, while one of the Italian delegates, representing the Registro Italiano, told us that the new Italian rules definitely prohibited the use of this system.

Referring now to the switchboard and the preference circuits, this is an interesting example of the difference between land and marine practice. It also illustrates the flexibility and convenience of electric control. There is another form of this preference or selective tripping system with which I have been associated on the Continent, in which contactors are used for the circuit breakers for the feeder circuits. It seems to me that this offers some advantage in that the tripping circuits are simplified, because they can be operated directly on the operating coil of the breaker. In that system the dynamo breakers also are of the contactor type. I think this offers an advantage in respect of convenience of operation, by push button, and it is claimed that the use of contactors prevents the inadvertent closing of a stationary dynamo on to the busbars, because each closing coil is excited off its own dynamo.

The authors rightly stress the importance of the steering gear as one of the most essential pieces of apparatus on the ship, and mention that these motors are usually duplicated. It may be of interest to mention that, in addition to the duplication of the motors and control gear, duplicate operating coils and essential apparatus within each controller are sometimes called for.

Turning to page 247, dealing with motors, starters, and controllers, I fully agree with the authors that simplicity and reliability are very essential, but I disagree with them when they advocate the use of automatic starters "on every possible occasion." Instead of the word "possible," I think "suitable" would be better. Every occasion is a "possible" occasion, but not necessarily a suitable one for the use of automatic starters. The suggestion to make extensive use of automatic starters is to some extent nullified by a portion of the paragraph which follows it, and which perhaps might raise a doubt as to the reliability of such apparatus. In the phrase "so that repairs or replacements can be readily effected when necessary" I think "if" should be substituted for "when."

* W. J. Belsey: "Alternating Current for Ships' Auxiliary Machinery," paper read before the Institute of Marine Engineers, 13th March, 1934.

Coming to page 248, dealing with the "common" or "plural" and the "Uni-start" starters, I quite agree with the authors and with Mr. Allan as to the advantages of the two systems, which in essentials are practically the same. There are certain points, however, about which I should like to ask for information. The plural-starter system apparently uses a starter with a common resistance for a range of motors from 5 to 50 h.p. Does this provide a sufficiently close grading of resistance to provide a reasonably graduated start of motors of so widely differing sizes, and varying starting loads? In the other method which is referred to—the Uni-start system—the sizes of motors are divided over the two starters, one from 5 to 15 h.p. and the other, say, from 20 to 50 h.p., in which case a more close grading of resistance can be obtained. One hears criticisms of the common-starter system on the score of cost. It has been claimed, by users who are in a position to know, that the overall cost (including the cost of installing and cabling) is no higher than that of installing separate units. On the other hand I have heard it said (and I have seen figures which would appear to prove it) that the overall cost is higher—the cable runs are more expensive. The cost of the switchgear is very little different as between the conventional complete starting panel and the common-starter system, but I think that the overall cost depends largely upon the lay-out of the pumps and motors in the engine room. I have here a plan of a motor-ship engine-room which shows all the pumps arranged in a symmetrical row across the forward bulkhead, and the switchboard is on a gallery immediately above it. In this case the economy in cable-runs would be pronounced, but it might not obtain if the pumps were scattered about over the engine room. It would be interesting to have the authors' views on this point. Again, it is necessary to run back to the switchboard from each motor four or five control wires, including the shunt-field lead, which are unprotected. This seems to be an objection which some people raise against the system. Another criticism is that it is too vulnerable, i.e. that it "puts too many eggs into one basket." Also, we now and then meet the criticism (in most cases I do not think it is of any substance) that after a complete stoppage the auxiliaries cannot be started up sufficiently quickly with the common-starter system, because they have to be run up one after the other. Incidentally, in this connection the Uni-start system has an advantage, in that both the starters can be used at once.

Another form of centralized control with which I am familiar, and which follows the general principles of the centralized fan controllers which the authors showed on the screen, is that in which automatic starters are used for the essential auxiliaries, and a centralized push-button control board is placed in a convenient position, sometimes on the switchboard, so that the essential auxiliaries can be started from a centralized position without any difficulty. I have seen this system used with great success from the operating engineer's point of view, and I should like to have the authors' views on it.

One of the last of the authors' slides showed side by side two forms of switchboard; on the right was the steel-fronted switchboard for the propulsion-motor control, and on the left was the ordinary switchboard

with open-type switchgear on the front. The steel-fronted board looked a cleaner and more workmanlike job. It is of course necessary to use the steel-panel, or cubicle, type of construction with all live parts at the back, for the propulsion gear, on account of the voltage; but we know that the steel-fronted (or "dead-front") board with all the apparatus at the back and instruments and handles only on the front, is in almost universal use in Continental vessels. It would be interesting to have the authors' views as to the advantages of this method of construction. As Lloyd's Rules and the I.E.E. Regulations at present stand, it is hardly possible to employ that construction in this country because, for one thing, to fit a fuse behind the board is prohibited.

It would be interesting to have the views of the authors upon the danger of fire, a matter which is very much to the fore in the public mind at the present time. I suggest that possibly the use of an automatic fire pump and the sprinkler system will be more extensively employed in the future.

Dr. A. M. Robb: In the section dealing with d.c. Diesel-electric drive (page 255) the authors state "The addition of the electrical transmission has enabled economical values to be selected for the speeds of the engines and the propellers. A further invaluable advantage is found in the fact that the engines run in one direction only at constant speed, and are not subjected to frequent starting and stopping when manœuvring is being carried out." In the first Diesel-electric ship built for service in this country the choice of Diesel-electric propulsion was determined mainly on the question of propeller speed; in that ship the propellers run at 440 r.p.m., while the engines run at 330 r.p.m. When, some 3 years later, a second Diesel-electric ship for the same fleet was under consideration the question of propeller speed had fallen back into a secondary position; the determining consideration was the elimination of manœuvring of the Diesel engines. Incidentally, there is another advantage in Diesel-electric drive to which the authors do not refer; but the omission is pardonable since the advantage is one that concerns especially the naval architect. The advantage lies in the ability to divorce the propelling plant from the generating plant, with considerable increase in the possibility of attractive lay-out of the ship. In some types of boats for excursion services that advantage alone is adequate justification for the adoption of Diesel-electric drive.

The adoption of electrical transmission does not necessarily entail serious, if any, increase in weight of machinery as compared with direct Diesel drive. The relatively high-speed, unidirectional Diesel engines that are suitable for Diesel-electric drive, and the comparatively light generators that result from the adoption of relatively high speed, may together be so much lighter than the direct-drive Diesel plants that there is still weight to spare for the provision of the motors without the total machinery weight being widely different from that for the direct-drive Diesel plants. Moreover, the relatively light Diesel engines and generators may be mounted on springs—with a further advantage as regards freedom from vibration.

As a final point in the general consideration of Diesel-electric drive, it is necessary to comment on Mr. Freeman's rather "faint" praise of electrical gear. It is a matter of interest that in the two Diesel-electric ships on which the foregoing general remarks are based there have been no electrical troubles; the troubles, all of minor concern, have been entirely mechanical.

It is now necessary to deal with one or two points of detail. The first of these is the question of control. With bridge control—incidentally, still another advantage of d.c. electric drive—there is always a tendency for the officer to slam the controller from "full ahead" to "full astern" without regard for what will happen down below. The authors indicate that that is a matter of no importance; it is possible to fit an anti-stalling relay which safeguards the engine. It so happens, however, that I have watched an engine which normally runs at 500 r.p.m. jumping up and down from 450 to 550 r.p.m. in its endeavours to follow up an anti-stalling relay, and this prompts the suggestion that the proper method of safeguarding the engine is to introduce a delay directly in the controller. A simple means of doing this would be to adopt an Admiralty type of telegraph controller, with one revolution of the handwheel for each step of the controller. This would prevent overloading of the engine by making it quite impossible for the officer to vary too rapidly the propelling-motor load, and by the adoption of such a type of controller some electrical devices could be eliminated.

Finally, a question is raised by the following sentences on page 257: "For normal running in twin-screw vessels, it is usual to keep the port and starboard sides separate. It is advisable, however, to be able to run both motors in series with one generator if required. In this case both propellers must run at the same speed, but one can be ahead and the other astern." In that last sentence there is rather more than appears on the surface. The authors will agree that it is difficult to get a ship captain to appreciate fully the limitations on the handling of the bridge controls which are involved when running on one generator and two motors. Moreover, there are possibilities of serious confusion in the interpretation of orders if the ship is on engine-room control with only one generator in service. Hence it seems desirable to consider an arrangement which does not impose any limitation on the propellers, other than a reduction of total power, when only one generator is in service. That arrangement would be, in a twin-screw 2-engine installation, two "half" generators on each engine, with the two forward "halves" connected in series to (say) the starboard motor and the two after "halves" connected to the port motor. Then when one engine is out of commission the effect is merely that of reducing the voltage of the motors, without any effect on their independence. With such an arrangement, and the adoption of the constant-power system illustrated in Fig. 10, it would seem possible to cut out some more of the automatic devices for which at the moment the electrical engineer seems to display an undue affection.

Mr. C. R. Bolton: In connection with the ventilation of spaces below the water line, is there any regulation concerning the amount of air to be supplied? In particular, the authors showed a slide of a telephone exchange for two operators. As this appeared to be without

natural light and ventilation, it would be interesting to know what number of changes in the atmosphere, per hour, is allowed for in a case like this.

Mr. A. G. S. Barnard: On page 244 the authors talk of the load of the vessel being divided deck by deck; I should like to know whether they mean from fore and aft of each deck, because I think it would be a better proposition if the load were divided between the watertight bulkheads, thus avoiding the trouble of running the cables through the latter.

It is disappointing to find on page 244 that the description of the engine room is condensed into 10 lines. The engine room to-day is really the most interesting part of the ship, as where possible all auxiliary equipment is driven by electricity. The authors mention the advantages of the Uni-start system for engine-room auxiliaries; I very much doubt the claims they put forward. If we take the area shown for the starters on the slide, plus the extra length of the main switchboard, I do not think it represents a gain of a square foot of space. The trouble to-day is that we speak and think of floor space in an engine room, instead of thinking of the bulkheads where these starters can be situated. It is only necessary to have the push buttons in the engine room, and these do not require much space.

Turning to the question of ventilation (page 245), I should like to ask the authors whether they have taken any precaution in case of fire. Can the fans be shut off in the section which has been notified to the bridge, or has one of the ship's personnel to stop the fans individually? I think it would be a great advantage if, the moment the bridge was notified of a fire in any section, the fans could also be stopped in this section from the bridge.

It is stated on page 246 that, owing to the temperatures to which cargo winches and motors on the top deck are subjected, provision should be made for breathing. I should like to know what provision the authors have in mind for this purpose, as we meet with the same sort of trouble.

On the same page the authors speak about simplicity in electric control gear on board ship. From the paper one imagines that the contactor gear is the basis of this "simplicity"; if one talks to the average marine engineer about this form of control, however, it is soon obvious that one is taking him out of his depth.

Under the heading of "Motor Design" it is stated that for deck machinery, forced-draught fans, etc., totally enclosed or pipe-ventilated motors are preferred. Can the authors inform us where they intend taking the air intake pipe of the motor to?

As regards cables, the authors state that no cable smaller than 3/·029 in. should be used. Does this apply to core cable as well? This is the type of cable which receives the most handling; it is generally used on the low-voltage circuits, which are more abused than any other circuits on board ship.

I have heard that in a vessel driven by four propellers the load cannot be evenly divided between the four motors. Is this due to the design of the motors or propellers, or is it due to the design of the vessel as a whole?

Mr. V. L. Farthing: The authors mention a special type of bearing lubrication, and I should like to know exactly what this is. In one of the slides showing the turbine room of a ship there appeared to be very little head-room. I should like to know whether this is the case; if so, the room would be uncomfortably hot for the operating engineers.

Mr. R. H. Bales (*communicated*): On page 243 the authors state "To meet Board of Trade requirements on passenger ships a small Diesel-driven generator, called the 'emergency generator' is installed. . . ." I should like to point out that there is nothing in the Board of Trade requirements to the effect that the prime mover driving the emergency should be a Diesel engine; and in fact I think it is quite well known that many of these emergency sets are petrol-paraffin-driven. The great merit of the petrol-paraffin sets is that they can be started by hand, and without any large amount of fuss, as is sometimes experienced in starting Diesel engines from cold. As a matter of interest, I would point out that the new L.M.S. boat now building at Messrs. Harland and Wolff's yard, Belfast, is being fitted with a petrol-paraffin emergency set.

Mr. W. J. Heaton (*communicated*): The opinion seems to be generally held that a.c. commutator motors are used simply for variable-speed drives; this of course is not altogether true, as such motors are very useful when running at fixed speeds for power-factor correction purposes. I have in mind a case where one of these motors was installed to run at 0·9 power factor leading, when all the other motors were of the induction cage type and the supply (from a small private plant) was limited; the benefits derived from the new motor were enormous, both from the current-saving and the voltage-stability point of view. Would it not pay to employ induction motors for marine propulsion, in conjunction with a commutator motor having a leading power factor sufficient to balance them; or, alternatively, where the machines are built in two separate halves to have one half an induction motor and the other a commutator motor? One big advantage of this method is that the d.c. excitation necessary for synchronous motors is dispensed with. Other advantages to be gained are pole-changing and cascade operation for reduced speeds; this saves either (*a*) running two propellers idle (when there are four altogether), or (*b*) reducing speed on the main turbo-generators.

The following is another way of overcoming the power-factor trouble. Let us suppose a ship is driven by four induction motors and the generating plant consists of two turbo-alternators. Instead of using the orthodox alternator for both turbine sets let us use an asynchronous or induction generator for one; this will generate, if properly designed, at a power factor sufficiently leading to balance the lag of the induction motors. The generating plant can now be arranged so that the alternator is driven by the high-pressure turbine and the asynchronous generator by the low-pressure turbine. Such an arrangement will save a set of governors, since this type of generator does not require synchronizing but will run at some speed in excess of that of the alternator. Thus by suitable design the power factor can be made to approach unity at all loads.

Mr. J. K. Wilkie (*communicated*): On page 243 it is stated that, to meet Board of Trade requirements, a

small Diesel-driven generator, called the "emergency generator," is fitted. There is no obligation whatever for shipowners to fit Diesel-driven emergency generators, and the latest practice would appear to be against this. The "Empress of Britain" (the new Elder Dempster boat, building at Messrs. Harland and Wolff's), the new L.M.S. boat (building at Messrs. Harland and Wolff's), and the "Queen Mary," which may be taken as fairly representative of the latest types of ships in the British merchant service, are all being fitted with petrol-paraffin emergency sets.

The petrol-paraffin set possesses the great merit of hand-starting and absolute reliability. The fuel systems do not require to be specially primed before starting. No trouble is experienced through the engine being cold, and intricate and complicated fuel pumps are not required; no compressed air is required. The only objection of moment advanced against these engines is that it is necessary to start them on petrol. All valid objection can be overcome, however, by carrying the petrol in small sealed copper cylinders, which are inserted into a special chamber, and perforated like "Sparklet" cylinders. After a few revolutions on petrol, the engine can be turned over to paraffin.

Only recently, in Liverpool, a well-known engineer-superintendent arrived at the South Liverpool Docks to find that an engineer, having incorrectly adjusted his air valves, had lost all the air in the ship, and not only could the main engines not be started but the emergency set failed to start on the compressed-air supply available. The only method of getting the main engines started was to employ a local firm of scaling merchants, who brought down a portable compressor, and after many hours' work the lighting set was at last brought into operation, and this in turn enabled the main compressors to be used.

The Authors' Reply to the Discussions at Glasgow* and Liverpool.

Messrs. C. W. Saunders, H. W. Wilson, and R. G. Jakeman (*in reply*):

Glasgow.

In reply to Mr. Butler, whilst the head room in turbo-electric ships is small compared with that required where other forms of drive are in use, the space allowed is adequate for lifting, overhaul, and so on.

Water-cooling of turbo-alternators was suggested some years ago, but no progress was made in this direction. We have not heard of its being considered for ship work. There is no technical reason why the heated air from the auxiliary generators should not be used for combustion purposes in the boilers, but it is doubtful whether the saving effected would justify the complication of the trunking. For the high-voltage propulsion generators it is very advisable to use a closed-circuit system of cooling to ensure the use of clean air. The figures in Table 1 are only approximate and there is no such improvement in efficiency as would appear.

We entirely endorse Mr. Nielson's remarks in reference to fire aboard ship, and in all ships with which we have been connected, from long before these disastrous fires until to-day, the installation of the cable and gear has always been considered from this point of view. To-day, with the precautions that are taken, the risk of fire on British ships is probably much less due to electrical causes than to other causes under suspicion.

We thank Mr. McNee for corroborating a number of the points brought out in the paper. We maintain that the advantage in manœuvring in the case of Diesel-electric propulsion is very pronounced. The electric motor on the propeller shaft is probably the ideal reversing engine or machine because of the even torque distributed all round the air-gap, and we think the rolling-mills in the country demonstrate this. Nothing could be simpler in operation, because whether the control is from the bridge or engine room the operation is the same as the ringing of a standard telegraph and with properly designed gear can be as quick as desired, because the actual reversal takes place always just as rapidly as the machinery can safely do it. We do not mean to imply that because of this advantage the Diesel-electric drive is the best for all cases.

The addition of generator and motor is not considered to detract any more from the reliability of the machinery for propulsion than do the electrically driven auxiliaries.

The comparison of the turbo-electric with the geared turbine drive has been fully dealt with by one of the authors in a paper read before the Institute of Marine Engineers, and the comparative consumption curves show almost equal results.

Turbo-electric consumptions can never get down to the figures for straight Diesel sets any more than geared-turbine figures can, and neither can Diesel-electric figures unless Diesel-engine makers can reduce their consumption by utilizing higher speeds. The figure of 25 per cent extra cost mentioned seems incredible because, as stated elsewhere and also in the above-mentioned paper, provided the curves are accurate (and they have not been shown to be otherwise), then the comparison is between turbine and gears versus turbo-alternator, control gear, and motor, and it is doubtful whether the cost of either would much exceed 25 per cent of the total installed machinery in the ship, when one considers the cost of the condensers, boilers, seatings, shafting, propellers, auxiliaries, funnels, etc., and the cost of installation.

Mr. Austin's remarks on winches are very valuable on account of his wide experience. Our experience is that contactor control, when properly designed, actually has similar characteristics to steam. His remarks on the mileage of cables apparently refer to the alternative use of the constant-current system for auxiliaries. Although the latter perhaps has advantages on small ships, complications arise as the number of motors increases. This was felt to be too specialized a subject to deal with in the paper.

Referring to Fig. 10, we agree that curve (*b*) does not represent constant power, but it is called a constant-power curve because it approximates to the constant-power curve over the working range. In the same way

* The Glasgow discussion will be found on pages 276–281.

the constant-current curve does not represent constant current from end to end. We do not agree with curve (*c*) in Fig. B. If curve (*c*) in Fig. 10 is converted into torque and r.p.m. it remains exactly the same to a different scale for a constant value of the motor field current. Under these conditions, the voltage is proportional to r.p.m. and the current to torque.

We note that the response of the self-protecting dynamo is much more rapid than that of the standard machine. A proportion of the correction, however, is produced by a change of flux, so that the response is by no means instantaneous. It is difficult to conceive that such a response is more rapid than that obtained with relays.

We agree with Mr. Bentley that since the advent of the Diesel engine the use of electrically driven auxiliaries has increased rapidly, and we maintain that these have now established themselves firmly with the shipowner, who is the final judge. This applies to most classes of vessel, although unfortunately not yet to all. Most of the insulated ships built during the last few years have electric winches, and in these ships the chilled cargo has to be moved very quickly. All of the advantages of other forms of drive have been repeated in the modern electric winch, without the "field days" and upkeep charges associated with the other drives. This applies also to capstans and windlasses.

We consider that the automatic starter is the best possible means of starting a motor without misuse on the part of the operator, and we would suggest that Mr. Bentley's remarks regarding controllers should be noted by electrical designers because there is no doubt that controllers for marine use must be of the most substantial design.

We agree that with correct initial design of the Ward-Leonard systems, interlocks and safety devices can be reduced to a minimum, and that this is very desirable.

Liverpool.

Mr. Freeman remarks that electric transmission of power at sea has come to stay and that it will have to be given full consideration when new passenger tonnage is being considered. We are of the opinion that after a full unbiased authentic investigation it will be found that turbo-electric drive is so close to, if not equal to, other forms of steam drive in the essential features such as first cost, weight, space, economy, and upkeep, that its inherent advantages in other directions will in many cases sway the decision by the owner in its favour.

The question of full power astern does not affect the steering gear and rudder, because its real advantage is to take way off the ship in the shortest possible time and not to drive the ship at the maximum speed astern. During all manœuvring full power ahead and astern is always without much way on the ship, and full power astern in emergency is only used until the ship has stopped or is moving slowly astern.

Unfortunately, no steam-driven machinery at present can show as low consumption figures as oil engines, and bunkers enter into the problem very much. This must be looked upon as one of the disadvantages of all steam drives, but for some trades it may be quite a small one.

The relative costs mentioned should be investigated further, because if the curves shown in Fig. F are substantially correct then the comparison is as mentioned in the replies to Mr. Constable and Mr. Wilson. Presumably the relative costs are for the total machinery installed in the ship and, if this is so, then the 19 per cent difference in the two steam examples will amount to quite a large sum. It would be interesting to know what the figure is for these items. The consumption figures mentioned must be corrected to exactly the same steam conditions of pressure and temperature, feed-heat temperature, etc., but here again Fig. F is illuminating.

The transmission loss can be stated more accurately than as being from 8 to 15 per cent. It is, of course, dependent on the power, speed of turbine, and propeller revolutions, but generally speaking it can be taken as 9 per cent for medium powers. If 2 per cent is taken as a gear loss, then the net comparative loss is 7 per cent. With the choice of high-speed turbines and any required propeller revolutions, perhaps this 7 per cent could be still further reduced. It should be stated that these percentages are conservative.

With alternators and a.c. motors it would not be found that if a coil broke down the whole machine would be burnt out, and it would not be necessary to remove the machine from the ship for repairs.

In reply to Mr. Allan, the use of enclosed, ventilated, drip-proof motors is probably the biggest factor in keeping down the first cost for all auxiliaries, and we think that experience with ventilated generators and motors that have been running for years afloat has demonstrated conclusively that, given reasonable care in keeping them clean, they have justified their use. We can go further and say that in cases where cleanliness has not been exercised and after a number of years—10 to 12—practically no major repairs have been necessary but simply a good cleaning out, the machines have at least the same period of life ahead of them, probably a great deal more. Proper supervision and periodic cleaning should be all that is necessary.

The use of essential and non-essential circuits is not intended to keep the load balanced on the generators but simply to reduce the total load by tripping the unimportant circuits in the hope that the fault is in one of them. Should an engine or dynamo fail, this throws an overload on to the other machine. This overload trips the unimportant circuits, and as the total load of all essential circuits should not exceed the full load of one machine this ensures that one generator will keep the ship going.

We believe that the life of modern cables is nearer to our estimate than to Mr. Allan's, although we agree with him that cable as fitted 12 or 15 years ago had a life as stated by him. This is undoubtedly a very important subject, constituting as it does probably the weakest link in the electric chain aboard ships. We hope that the combined experience of the Admiralty and the merchant service, together with the help given freely by the cable manufacturers, will further strengthen this link until there is no doubt whatever that the life of the cables is at least equal to that of the ship itself.

In reply to Mr. Livesey, we consider that the Institution, in combination with the Institute of Marine Engineers, might use its influence with the Board of

Trade, to establish the status of electrical engineers at sea.

The question of single-pole versus double-pole installation is quite controversial, but in this country the consensus of opinion is for the latter. One "earth" in the former means a shut-down, whereas two, one on each pole, are necessary before a shut-down occurs on the latter. Several "earths" may be experienced on one or other pole in the latter without a shut-down. Earth detectors are fitted and, providing no shut-down occurs, the "earth" can be cleared almost at leisure, but of course it should be cleared at once. The double-pole installation undoubtedly constitutes a stand-by up to a point. It of course requires double the cable, with attendant increase of first cost. The controversial point of corrosion of plates, condenser tubes, etc., is also bound up in the choice.

With the preference-circuit system, it is almost common practice to fit circuit breakers to circuits of 200 amperes and upwards, and these have tripping coils. Below 200 amperes the circuits are often grouped together on to a circuit breaker with tripping coil. The system is therefore quite flexible. All generator circuit-breakers should be fitted with reverse-current tripping coils and a "loose handle" fitment. The breakers can be operated by means of push-buttons as described by Mr. Livesey.

The grading of the starting resistance of the plural starter, in conjunction with the variable speed of the motor driving the drum, has been proved in service to be ideal. We have always had in mind that the rate of acceleration of a motor is very often far from being an electrical consideration, but is sometimes entirely governed by the type of auxiliary being started. A fan can be started fairly quickly, a centrifugal pump not quite so quickly, a compressor very much more slowly, and any form of separator even more slowly still. Whilst the governing feature is the range of powers to be started, and this has been very successfully catered for over the range mentioned, it has been possible to some extent to cater for the other requirements as well.

The relative cost of the common starter is dependent on the number of motors that can be put on to it, until if sufficient motors are available it might easily prove cheaper than individual starters, and this is quite possible in a single engine-room, where the auxiliaries are spaced all round the wings and at the forward and after ends. Frame spaces can be taken out of engine rooms and put into cargo spaces, owing to the use of the common starter.

With individual starters the eggs for any one unit are in one basket, but with the plural starter there are two baskets as far as the starting resistance and its controller are concerned. As mentioned elsewhere, all the important auxiliaries can be restarted in 2 minutes. The centralized push-button control is not recommended for engine-room auxiliaries, as all important auxiliaries should be started locally at the unit to ensure that

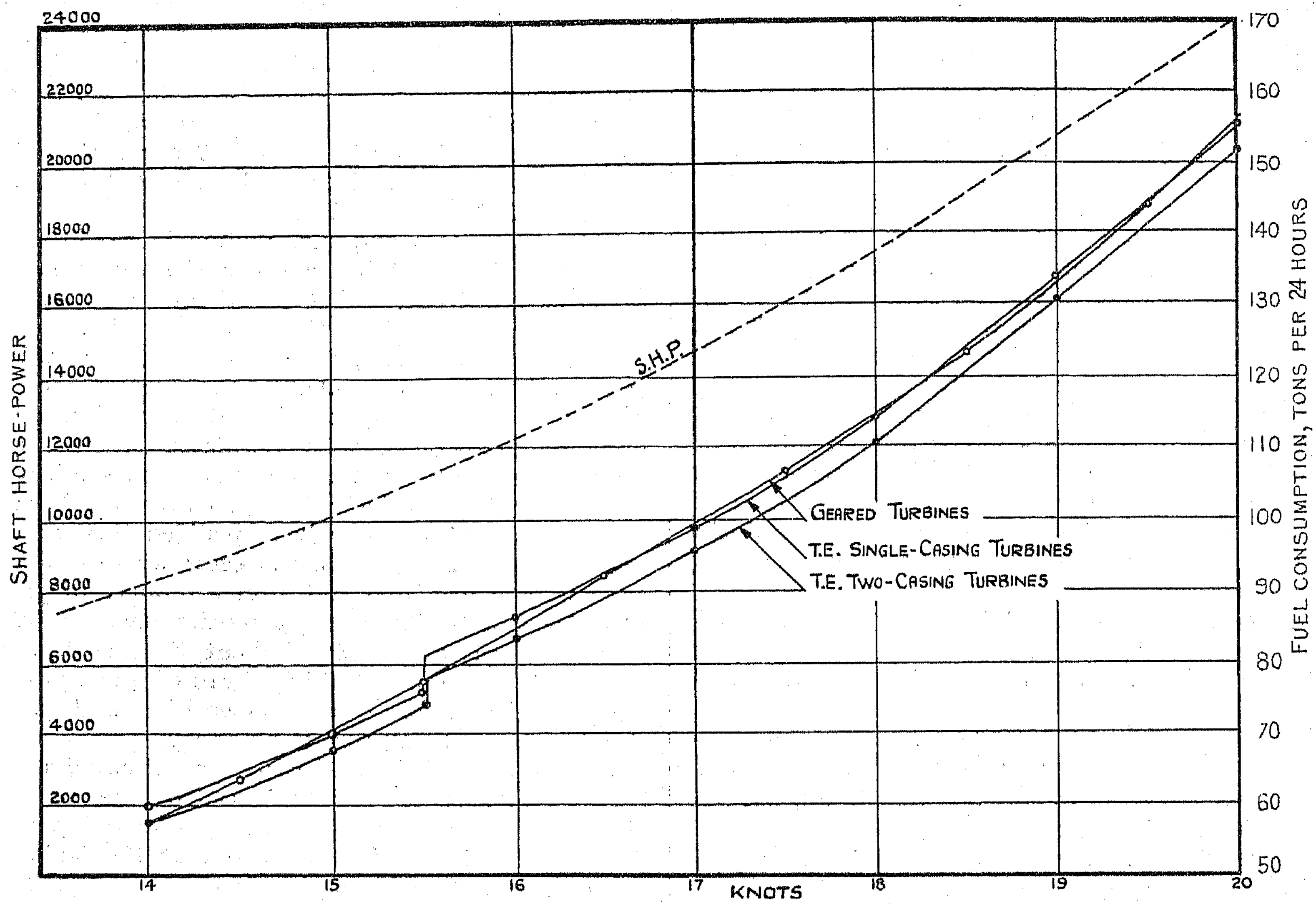


FIG. F.—Fuel-consumption curves from 24 000-s.h.p. twin-screw vessel, showing two turbo-electric comparisons with geared turbine.

everything is functioning properly, not only on the electrical side but on the mechanical side also. Our view on switchboards is that "dead front" boards hide away a lot of switchgear which is better placed if its operation can be observed and where it is more easily cleaned, overhauled, or adjusted. Where the voltage is high the "dead front" board must be used. The question of fire has been dealt with elsewhere.

We thank Dr. Robb for his favourable remarks on Diesel-electric drive for certain types of vessel and we agree with them. With regard to bridge control we are not in agreement with the suggestion made, and we do not think that the variation in the engine revolutions mentioned in any way approaches the final figures that can be obtained when final adjustment of the anti-stalling relay has been carried out. In a single-screw job of exactly half the power of the quoted example, which was a twin-screw job, during a full reversal with such power that the two Diesel generators were all out, the engine revolutions varied only $2\frac{1}{2}$ per cent, viz. $1\frac{1}{4}$ per cent up and down, and this was the maximum, the later fluctuations being even less. The quoted example can very easily be brought to the same percentage, for an equal governor.

Bridge control should impose no more restriction on the captain than the standard telegraph does, and there should be no qualifying instructions. He must be able to put his controller to where he wants it, immediately see on his propeller revolution indicator that the propeller is commencing to fulfil his order, and then turn to his steering wheel to alter the ship's rudder to his requirements. If his attention is demanded any longer by the controller, then bridge control is a doubtful and debatable feature.

There is bridge control fitted aboard existing Diesel-electric vessels which fulfils these conditions, and no matter how quickly the controls are reversed the actual reversal of the power is always carried out at a rate that is adjusted to suit the machinery installed without any overload whatsoever.

The question of running two propellers off one Diesel generator in a twin-screw ship (the other engine being out of action) is worthy of consideration. Where it is accepted that under this condition it is sufficient that both propellers are always ahead and astern together and at the same revolutions, the control gear is the simplest possible and there is very little of it. The vessel is, in effect, a single-screw job but with two propellers. Where it is demanded that one propeller should be ahead when the other is astern, again at the same revolutions, then the control gear becomes a great deal more complicated, and, what is more important, the captain must remember certain instructions in the use of his controllers and use them in a certain way, otherwise he will not get what he wants from his propellers. With the first alternative the captain would act exactly as he would do on any other ship, viz. with one engine out of action he would use only the telegraph or control of the sound engine, but he would have both propellers ahead and astern together, instead of only one as in the case of any other type of drive. Further, with an engine suddenly failing, at predetermined low revolutions, both motors would automatically be put on to the sound engine with the facilities mentioned above.

We agree with Dr. Robb that the suggestion of dividing the propulsion generators into two halves has much to recommend it. There are certain mechanical difficulties, since two propulsion generators and one exciter are coupled to the engines in line, but these can be overcome although the sets would naturally occupy more space than single generators. It would still be necessary to use switches to cut out either of the generators as required. Even with the constant-power system anti-stalling relays are desirable owing to the comparatively slow change of the magnetic fields. However, these would not be called upon to act so frequently as with shunt generators.

The ventilation of spaces referred to by Mr. Bolton is carried out by means of supply and exhaust fans through trunking, and the number of changes varies according to the space and its function.

We regret very much, and apologize to Mr. Bales and Mr. Wilkie for, our loose wording in connection with the emergency generators. We should have used the term "internal-combustion" instead of "Diesel."

Replying to Mr. Barnard, the division of the load, deck by deck, or otherwise, is a particular problem for each vessel. The system may take the form of a ring main, or tree type, or separate feeders, and it is an example of the flexibility available that this is so.

The common starter has proved itself a space-saver in a dozen ships afloat and is being fitted for this reason, as well as others. It saves length of engine room in a fore-and-aft direction, which means a smaller engine room and so more cargo space, whereas the switchboard, which nearly always is placed athwartship, although longer will take up extra space in a direction where this is practically always available in any case. Again, even with the shorter engine-room, more space is available for overhaul of the auxiliaries because it is not always possible to mount starters on the bulkhead and some have to be mounted on the floor.

The facility for shutting down all fans from the bridge in case of fire, again demonstrates the flexibility of the electrical auxiliaries because the fans can be grouped on to circuit breakers on the switchboards with push-button trips at the bridge. It is really just an extension of the system where the fans are controlled in the engine room.

The provision of a small hole in the bottom of the totally enclosed deck motor is an aid to breathing and acts as a drain for sweating. No water seems to get in from the deck hose. Contactor gear is not the complicated gear that it is commonly thought to be and the marine engineer will gradually realize this as he becomes accustomed to it.

In the case of forced-draught fans and where pipe-ventilated motors can have access to a space in the same deckhouse, away from the ash and dust, they may be used instead of totally enclosed motors, which would be more costly. In multi-core cable it is not so essential to use stranded wire, as the cable is generally of a fairly large diameter and therefore not so easily bent sharply, but with single cable a single strand is more liable to

fracture than a stranded conductor. With four shafts it is the wake of the forward propellers on to the after ones, the angle of the "A" brackets, and the ship's form, that prevent the load from being equally shared by four equal propellers, whether turning inboard or outboard. It is problems such as these that demonstrate the advantages of the electric drive, because on the four-shaft jobs mentioned in the paper the shaft-horsepower meters showed these differences all the time, the effect of helm could be noted, and, by running the two outers off one engine and the inners off the other, the outers could be speeded up until the load was the same as on the inners and it was possible to obtain authentic data of power and revolutions over any length of time and under any conditions. With any other form of drive, indicator cards or torsion-meter readings would have to be taken and the time element would enter into them. It is very convenient to have four meters alongside each other, giving all the necessary information accurately under actual service conditions, with results for comparison with tank models 1/100 or 1/200 full size. With the port propellers on the port engine and the starboard on starboard, the propeller revolutions, inner and outer, are of necessity exactly the same but the load is different, the inner taking more than the outer.

In reply to Mr. Farthing, the disc-and-scraper type of lubrication has been used for a number of years and has proved very reliable. It is particularly suitable for propulsion motors because it functions positively at all speeds. Other types of lubrication are not always reliable at the slow revolutions which have to be worked to, sometimes for very long periods on end, for example in fog. The oiling device consists of a large disc on the shaft which dips into the oil as the shaft revolves. The oil picked up by the disc is scraped off at the top and fed into a trough which in turn feeds the oil on to the centre of the journal. The arrangement is shown clearly on Fig. 5 in the paper, the disc being immediately above the drain cock, and the scraper and trough are shown on the top left-hand side of the disc.

The ventilation of the engine room shown on the slide and in Fig. 4 is carried out by means of supply and exhaust fans situated on the top deck, and even in the tropics the temperature of the engine room seldom exceeds 100° F.

We agree with Mr. Heaton that power-factor correction can be obtained from fixed-speed a.c. commutator motors. Such motors are, however, expensive in first cost and in upkeep. If a.c. commutator motors were used for propulsion the number of brushes would be excessive and we consider that such motors are at present impracticable for large outputs.

An induction generator does not provide a leading current, but has to be provided with a lagging wattless current. This lagging current is added to the magnetizing current of the motors, and the total has to be supplied by the synchronous alternators.

A.C. and D.C. Auxiliary Supply.

In reply to many speakers at various Centres we agree that the choice of alternating or direct current has many arguments on both sides and it is difficult to predict what will be the practice in the future. There is no doubt that direct current is the more adaptable and can be used for any purpose desired. One of its disadvantages, as Mr. Constable points out, is that on large ships the currents to be handled become excessive and the cables are very large if a 220-volt supply is used. Dr. Kahn shows that this can be overcome to a certain extent by using a 3-wire d.c. supply with 440 volts across the outers. It should not be difficult to balance the circuits sufficiently well.

The chief disadvantage of alternating current is the fact that a large number of the motors have to be varied in speed. Although this is possible with a.c. motors the speed variation is not so convenient as with direct current. It has been suggested that instead of running centrifugal pumps at different speeds for different duties a constant speed should be used. In this connection the remarks of Lieut.-Commander Hobson on centrifugal-pump characteristics, indicating the discrepancy of as much as 20 to 30 per cent in estimating the pump service, are very illuminating and really go to the core of the problem of the use of constant-speed motors, whether d.c. or a.c. When these units were driven by steam engines it was very difficult to get authentic data to compare actual power used with estimated power, but with the vast number of units that are now electrically driven in the ship accurate measurement of power is not only possible, but available.

Pump makers are no doubt rapidly arriving at a position where their estimates based on experience will reduce the discrepancy to, say, 5 or 10 per cent, thus making a big step towards the constant-speed unit. Then the loss of efficiency and the probable increase in price of the pump material due to the much more heavy duty should be small compared with the saving in first cost and upkeep cost on the electrical side if the squirrel-cage motor could be used.

We would suggest that the shipowner and shipbuilder could profitably investigate with the pump maker the regrouping of the pumping duties. The same applies to the other auxiliaries in the ship.

Mr. Butler suggests the use of hydraulic clutches. These, used in conjunction with squirrel-cage motors, may offer a solution so far as deck auxiliaries are concerned, although at present they appear to be rather expensive, particularly in the smaller sizes such as those required for winches. Should the a.c. commutator motor be used then there is still the problem of first cost and upkeep and we consider that we should endeavour to make the complete change, if any change is made, and go over to the more robust and cheaper squirrel-cage motor. The question of magnetic hum may present serious difficulties, particularly where machines are situated in close proximity to the bridge or to passenger accommodation.

In reply to Mr. Denholm and Mr. Bentley, we do not consider that suitable torque characteristics for windlass and winch motors can be produced with a.c. machines at a reasonable cost, so long as the machines have to be variable-speed and reversible. Mr. Beaty's proposal to use alternating current for the hotel load and direct current for the motors might perhaps be feasible on large ships.

DISCUSSION ON

"THE PRACTICAL SOLUTION OF STRAY-CURRENT ELECTROLYSIS." *

Dr. W. G. Radley (*communicated*): The work described in Parts 4 and 5 of the paper implies that, in the author's opinion, the use of electrical drainage connections is one of the most hopeful methods of approach to the practical solution of stray current electrolysis problems. It must be emphasized, however, that these problems are primarily of an economic nature and that the case for electrical drainage as the cheapest solution is not perhaps so clear cut as might be gathered from the paper. Before an electrical drainage bond is connected between a conduit and the uninsulated return of a tramway system, detailed measurements of potential differences and of leakage-current distribution are made. In this connection it may be mentioned that simple pipe-to-rail potential measurements are not a very reliable criterion as to the electrolysis hazard. This is due to the fact that practically the whole of this potential exists between rail and earth, whereas the pipe-to-earth potential is the one giving rise to corrosion of the pipe.

The initial measurements ensure that the bond conductance is such that the conduit is maintained at zero potential, or at a small negative potential with respect to the earth, under all conditions of working of the traction system. Periodic measurements of the current in the drainage connections are necessary in order to guard against these connections becoming harmful with a change in the conditions of working of the traction system.

Careful investigation is also necessary as to the relation of the conduit which is to be drained to other buried pipes, etc. Drainage bonds have the effect of extending the return-current network of the traction system to the drained conduit. They can therefore increase considerably the probability of corrosion in neighbouring metallic conduits. It would be interesting to know what proportion of the savings indicated by the reduction in the annual number of cable faults shown in Fig. 11 was absorbed by the cost of investigations and measurements.

The Comité Consultatif International des Communications Téléphoniques à Grande Distance, in its recommendations as to measures to be taken for the protection of cables against electrolysis, points out the foregoing and other objections to drainage. These disadvantages, however, are considerably decreased in certain cases, for example, where only a single tramway route is concerned and this is followed closely by telephone cables without branches. Insulating joints in telephone-cable sheaths have been recently used in Italy as part of a scheme of protection employing drainage bonds. Such information as has been published indicates that the insulating joints are definitely advantageous and enable the distribution of current in the conduit system to be controlled more closely.

The putting of the tramway return-system into good condition must always be a pre-requisite to any scheme of protection involving electrical drainage connections between a pipe, or cable system, and the tramway return.

Inexpensive forms of pipe wrapping, layers of insulating paint, etc., do not provide a permanent protection against corrosion. In fact such insulating layers have often been found to be disadvantageous, since at the points where they become damaged the current is localized and a more intense corrosion takes place. In addition, when applied to telephone cables they limit the ease with which these may be drawn into and out of ducts. The flexibility given by a duct system is an essential requirement of the telephone service in Great Britain and would preclude, except in exceptional cases, the use of cables laid solid in bitumen.

In Section 1(*b*) doubt is cast on the utility of studying the nature of the corrosion products. In the case of iron structures this may be so, but with lead cable-sheathing there appears to be a strong case for a quantitative study of the corrosion products and of the water which has been in contact with them. There is little doubt that the composition of these products reflects the history of the corrosion and will give a reliable indication as to whether electrolysis has been primarily responsible for the damage. This method of approach is essentially suitable to cables in ducts.

Mr. C. M. Longfield (*in reply*): Dr. Radley raises a number of important points. He doubts whether the use of electrical drainage is the most economical mitigative measure that may be applied in practice, stating that an extensive survey is necessary for the proper setting and maintenance of drainage bonds. All that the paper sets out to show is that the alternative means of reducing stray-current corrosion, by means of limiting rail potentials to prescribed amounts, must be a very costly and arbitrary procedure, while electrical drainage, if effective, may be much cheaper. The costs of investigations are admittedly high in the preliminary stages; but, surely, thorough investigations would have to be undertaken before a traction authority was requested to spend very large sums of money upon mitigative measures which may not prove as effective as alternatives such as electrical drainage, and, therefore, I have not introduced the cost of these investigations which would have been undertaken whatever method of mitigation was ultimately decided upon. It must also be pointed out that the reduction of rail potentials may impose an annual expenditure upon the traction authority many times the cost of the investigations referred to by Dr. Radley.

When an extensive electrical drainage system has been installed, there is less need for conducting general surveys, and the proper maintenance of drainage bonds might reasonably fall upon the traction authorities, at least so far as maintaining them to some specified standard.

* Paper by Mr. C. M. LONGFIELD (see page 101).

Dr. Radley mentions that simple pipe-to-rail potential measurements are not a reliable criterion of the electrolysis hazard. He appears to have missed a very important point mentioned in the paper where the design of drainage bonds was discussed. In no case did I advocate the taking of these measurements as a guide to electrolysis conditions. The potential difference between pipe or cable and a local earth electrode was emphasized as the best means of deciding whether a pipe or cable was discharging current or not. I would refer Dr. Radley to page 103 in particular in this connection.

The method of designing drainage bonds outlined in the paper avoids the possibility of setting up the conditions which Dr. Radley refers to in the third paragraph of his communication, where he states that there is a probability of corrosion being set up in neighbouring metallic conduits by the use of electrical drainage. This danger does exist, and great care has to be taken to avoid such an interchange of current. The drainage of large, poorly insulated pipes is a much more potent source of danger in this connection than the drainage of telephone cables, for instance, especially if the latter are enclosed in well-drained ducts. I am familiar with the reports of the Comité Consultatif International des Communications Téléphonique à Grande Distance, and appreciate that drainage could be applied more easily in an area served by one traction system, but the results referred to in the paper have been obtained in an area where two distinct traction systems of some magnitude operate and render the design of mitigative measures extremely difficult. It is doubtful whether even London presents a more complicated problem than the one described in the paper.

Dr. Radley mentions the successful use of insulating joints in Italy. It is presumed that he refers, in particular, to Milan. The joints used in that city could scarcely be described as insulating joints. They are primarily drainage connections; and, again, I would say that, from a personal knowledge of that city, the problem there is not nearly so complex as the one mentioned above, and it is doubtful whether in the Milan example the cost of mitigative measures, say, per 100 cable-miles, is any less than that described in the paper.

I agree with Dr. Radley when he states that the tramway return-system should be put into good condition before other measures are embarked upon; but a definition of the term "good condition" leaves considerable room for personal opinion. It is presumed that Dr. Radley refers to the track work. From inquiries which I have made it would appear that European traction systems have suffered very much from faulty rail joints, and if Dr. Radley means by "good condition" careful maintenance of rail bonds, I agree with him wholeheartedly upon this point. In the investigations which formed the basis of the paper, the maintenance of track work was not a major issue, as rail joints both on the tramway and railway systems were maintained at a very high order of excellence.

I also agree with Dr. Radley when he says that an indifferent coating may lead to intense localized corrosion, and this only emphasizes the need for the development of a satisfactory permanent high-resistance coating for sub-surface structures. Such a covering has been developed for lead-covered cables, but a similar coating for large-diameter pipes has not yet been developed commercially. When electrical drainage is applied, any covering, however poor, is better than no covering at all, for reasons which should have been made clear in the paper.

Dr. Radley feels confident that the products of corrosion are a reliable index to the immediate past history of the cable. It is natural that one should turn to a chemical analysis for confirmation of other evidence of electrolysis attack, but I have not yet seen anything which leads me to believe that such an analysis will provide positive proof of one form of corrosion or another. If Dr. Radley, or any of those associated with him, can throw any light upon this important point, engineers in all countries dealing with this complex problem would welcome the publication of such information. However, I feel that, unless the whole of the surrounding conditions in any particular investigation were made known, the results would not be particularly helpful to those confronted with a different environment.

In conclusion, I should like to emphasize once again the advantages of co-operative effort, whereby the costs of alternative mitigative measures can be made known and studied dispassionately before any large-scale alterations are undertaken to existing plant. It is always very difficult for the servant of any one utility to grasp the difficulties of the other utilities interested in the solution of this complex subject, and it is for this reason that the employment of an independent engineer co-ordinating the activities of the parties interested in a particular locality can be of the utmost value.

EXPERIENCE AND CONCLUSIONS OF THE RUNNING OF THE CAPE TOWN-SIMONSTOWN ELECTRIFICATION OF THE SOUTH AFRICAN RAILWAYS.*

By J. H. Sprawson, Associate Member.

(*Paper first received 26th April, and in final form 17th September*, 1934.)

Summary.

This paper describes the 1 500-volt suburban electrification in operation between Cape Town and Simonstown. A general survey is given of the local conditions and of the system, and this is followed by more detailed descriptions of the difficulties experienced in operation.

The paper deals only with those difficulties which are connected with the rolling stock and which necessitated modifications to suit local conditions. The items reviewed cover pantographs, main motors, auxiliary machines, gears and pinions—with special reference to the importance of lubrication, bogies, and wheels.

Introduction.

The object of this paper is to review the troubles experienced, and the remedies applied, in the running of the Cape Town suburban electrification inaugurated in June, 1928.

The line covers a distance of 22·46 miles, with 26 stations, and 18·5 miles of this is double-track. The average daily number of passengers is now 74 000. The section is worked with 19 sets of coaches, which maintain a weekday service of 301 passenger trains in both directions daily. The trains are composed of 4, 6, and 8 coaches, made up of one motor-coach with three trailers, two motor-coaches with four trailers, and two motor-coaches with six trailers respectively.

The average headway during the morning and evening peaks is $2\frac{1}{2}$ minutes, and at midday 3 minutes. During the slack hours a 10-minute service, and on Sundays a 20-minute service, is maintained.

Climatic Conditions.

The extremely changeable nature of the climate subjects the equipments to a very severe strain. Spells of intense humidity of the atmosphere during the summer months, strong winds which carry considerable quantities of dust and dirt, and—along the coast-line of False Bay—fine blown sand and wind-driven sea spray, are encountered. The velocity of the wind at times attains 55–65 m.p.h. These sudden changes tend to affect adversely smooth working conditions.

Table 1 gives averages of temperatures, rainfall, and wind velocity, over the 5-year period (August, 1928, to July, 1933), as recorded by the official meteorological station at Observatory, 3·30 miles distant from Cape Town, which is much less exposed than the coast of False Bay. In Cape Town and along the track in the near suburbs, temperatures in excess of those shown in the official table have been regularly recorded. On the False Bay coast too, wind velocities are recorded in excess of the official figures.

Table 1.

	January	February	March	April	May	June	July	August	September	October	November	December
(1)	71·3	71·0	69·3	64·5	60·4	56·0	54·9	56·9	57·9	62·2	66·7	68·8
(2)	95·3	100·0	94·6	90·8	87·9	79·0	78·3	82·4	81·4	88·2	92·6	95·3
(3)	102·4	105·4	104·0	104·2	99·2	83·0	84·3	86·2	92·7	91·7	101·9	98·0
(4)	0·36	1·03	0·42	1·8	2·32	2·87	2·86	2·71	2·92	1·0	0·59	0·86
(5)	0·76	2·0	0·74	3·83	4·98	4·97	3·89	3·97	5·13	2·15	1·02	1·36
(6)	47	43	44	40	44	45	50	49	47	47	44	46

(1) Average monthly mean temperatures, °F.
(2) Average monthly maximum temperatures, °F.
(3) Absolute maximum temperature, °F.
(4) Average monthly rainfall, in.
(5) Maximum rainfall, in.
(6) Average monthly maximum gust velocity of wind, m.p.h.

Energy Consumption.

The total energy consumption for March 1933 was 2 588 376 kWh, representing 20·935 kWh per train-mile, 12·72 kWh per motor-coach-mile, and 93·5 watt-hours

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

per ton-mile. The consumption of energy is measured on the high-tension alternating-current side of the converting plant in the substations, and therefore the mean efficiency of conversion and distribution to trains should be estimated at 85 per cent. This calculation brings the consumption of 93·5 watt-hours per ton-mile measured on the a.c. side to 79·5 watt-hours per ton-mile measured on the d.c. side.

Energy consumption measured by an integrating kWh-meter connected on a motor-coach is as follows:—

(1) Six-coach stopping train, weight 254·7 tons.

(*a*) Cape Town to Wynberg, 12 stations, distance 8·07 miles, total consumption 176 kWh (=85·7 watt-hours per ton-mile).

CURRENT/TIME AND SPEED/TIME CURVES.

Fig. 1 is a reproduction of typical current/time and speed/time curves of a fully loaded 8-coach train with two motor-coaches, over the Mowbray–Rosebank section, mileage 0·59. This is taken from a test chart of an Evershed "traction recorder" giving continuous graphs from Cape Town to Simonstown of voltage, current, and speed. The voltage was fairly steady at 1 450 volts, and is not included in the graphs.

The speed curve gives the following average values: acceleration 0·56 m.p.h. per sec., retardation 1·5 m.p.h. per sec., maximum speed attained 29 m.p.h. All these values vary with the train weight per motor. The current curve gives an average notching current of 240 amperes in series and 440 amperes in parallel.

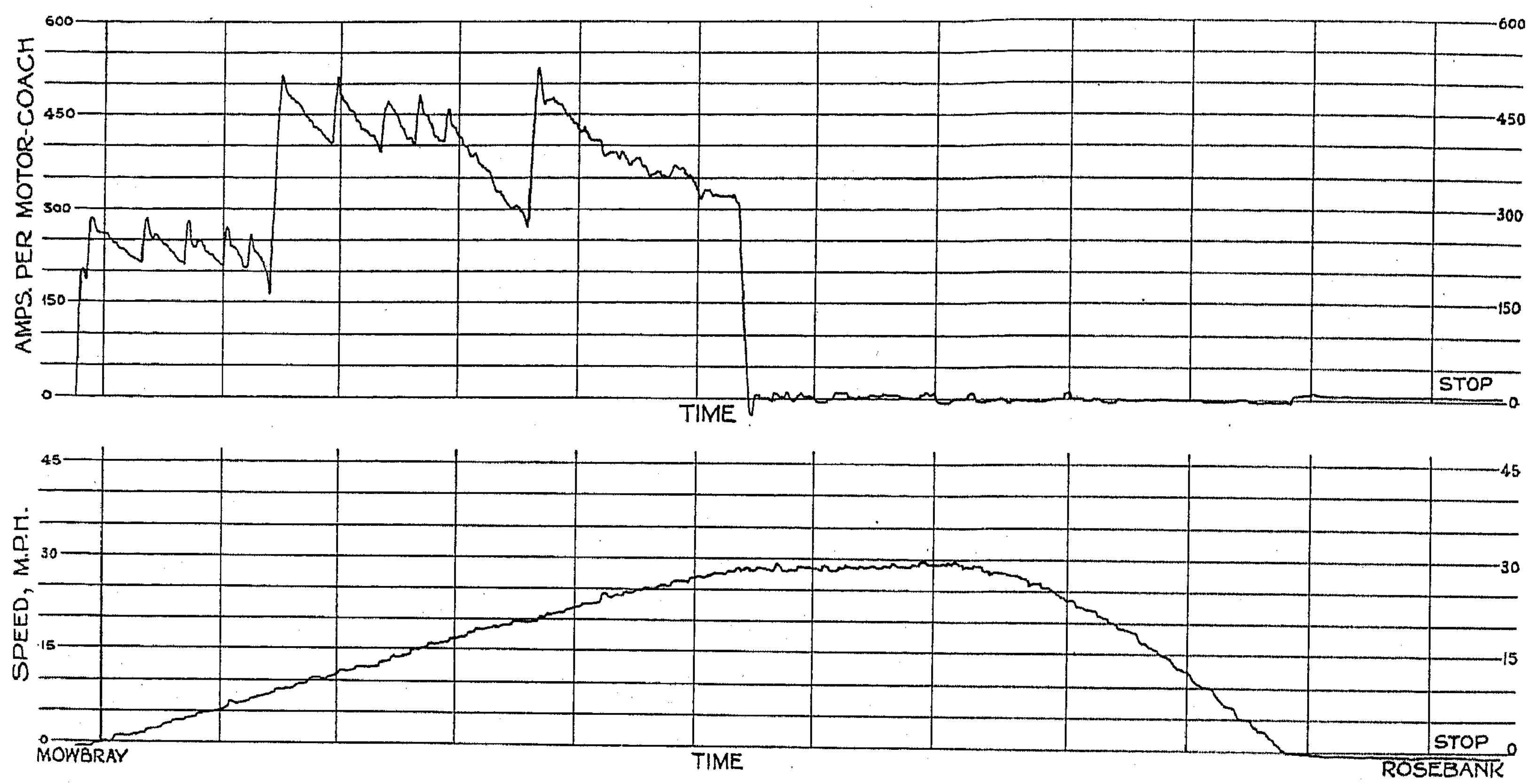


FIG. 1.—Records obtained on Mowbray–Rosebank section, for 8-coach train with two motor-coaches.

(*b*) Cape Town to Fish Hoek, 23 stations, distance 18·5 miles, total consumption 320 kWh (=68 watt-hours per ton-mile).

(2) Eight-coach stopping train with two motor-coaches, weight 321·8 tons.

(*a*) Cape Town to Wynberg, 12 stations, distance 8·07 miles, total consumption 221·6 kWh (=85·2 watt-hours per ton-mile).

(*b*) Cape Town to Fish Hoek, 23 stations, distance 18·5 miles, total consumption 407·2 kWh (=68·4 watt-hours per ton-mile).

It will be noted that the consumption for the 6-coach trains with one motor-coach to two trailers, on the Cape Town to Wynberg section, is approximately the same as for the 8-coach train where one motor-coach draws three trailers. In explanation of this it must be mentioned that on this section the time for the 6-coach train is between 18 and 19 minutes, while for the 8-coach train it is between 21 and 22 minutes.

These current values are constant throughout the whole run, as the minimum fall-off value is governed by the current-limiting relay.

PANTOGRAPHS.

The pantographs are of the usual design, spring-operated and vacuum-controlled, fitted with a double pan, each pan being independently sprung, and all joints being fitted with ball bearings.

Trouble was experienced with pantographs after the first year of service, caused through the excessive side sway and rocking movement of the coaches, which imparted whip and shock to the pantograph superstructures. Excessive strain was thrown on the brazed joints between the tubes and their sockets, resulting in broken joints and the breaking of the tubes where they enter the sockets.

The sockets on the main shaft, which form the anchorage of the moving structure, were the greatest source of trouble in this respect. It was also found, during investigation, that the brazing on many of the

sockets had only taken round the outer edge of the joint, instead of running well into the casting, thus causing a further weakness at these points.

The trouble with broken tubes was overcome by reinforcing the sockets on the main shafts. Lengths of steel tube, turned to a neat fit, were driven into the panel tube, and then riveted in place, both through the socket and through the panel tube itself. This modification was effected on all pantographs, and no further trouble was experienced with tubes breaking at these points. At this early stage, owing to excessive wear between joints and on pins, etc., a complete overhaul of the tube structures was carried out, when all the pin holes were bored and bushed, new pins fitted, and other minor modifications effected. In passing, it may be mentioned that the excessive side sway and rocking movement of the coaches was corrected (see page 590).

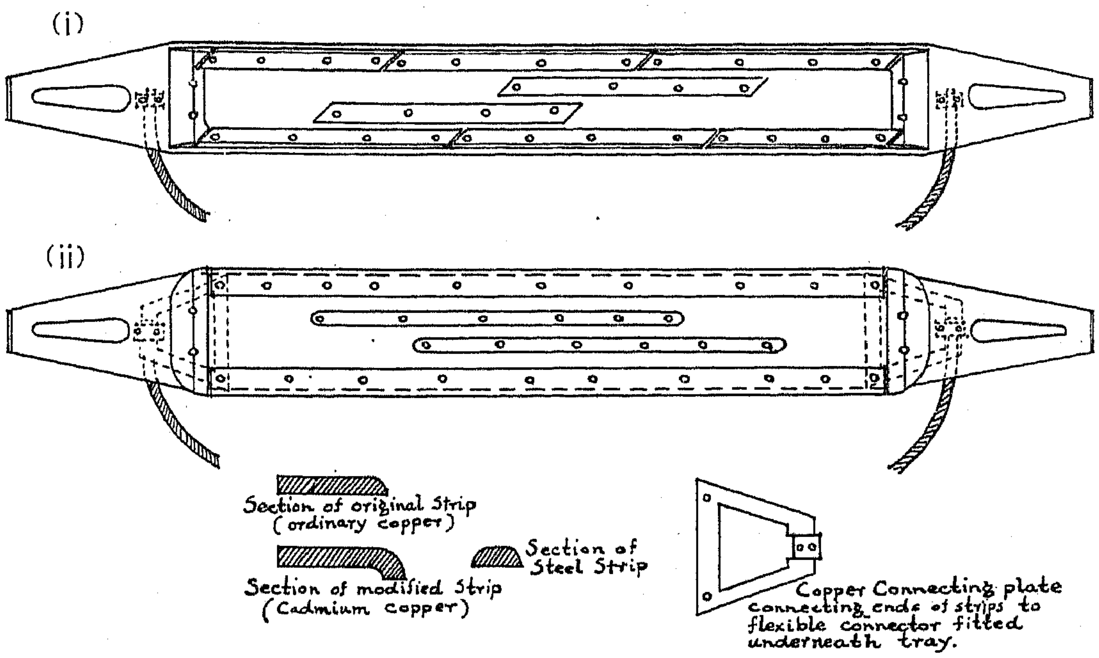


FIG. 2(A).—Pantograph collector tray, showing assembly of contact strips.

(i) Original design.
(ii) Modified design.

Contact Strips and Collector Trays.

Contact strips with a chamfered outside edge did not prove satisfactory, owing to the burning of the trays along the exposed edge, through arcing. This trouble was eliminated by the introduction of the type of strip which follows the radius of the tray round, projecting down below the top surface, thus protecting the edge of the tray from the arc.

After the first year of service it was noticed that abnormal rusting and pitting was taking place on the collector trays, particularly over the contact area of the strips. From the state of deterioration it would appear that electrolytic action was taking place through the interposition of moisture with other impurities between the strips and the tray. This condition was overcome by the use of modified stripping, and by protecting the surface of the tray with an insulating paint.

The modified stripping, shown in Fig. 2(A), provides for better conductivity and more regular wear. The use of cadmium copper, with steel strips between, has overcome the pitting and tearing action which was experienced with the original strips, and which is especially noticeable under certain climatic conditions.

The average consumption with the original strips was 1·3 strips per 1 000 miles. Special tests taken showed an average life of 15 400 miles per set of strips. With the modified strips, tests show an average life of between 25 000 and 30 000 miles per set.

Contact Pressure.

Local conditions necessitate a great number of varying heights of the contact wire, caused by the numerous road

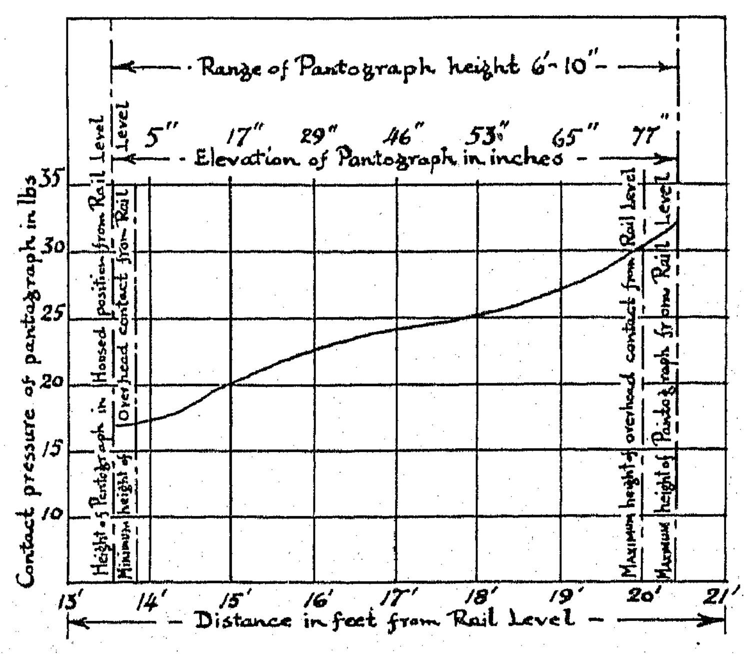


FIG. 2(B).—Curve of average set contact pressure of pantograph, showing variation of pressure with elevation.

crossings and overline road bridges en route, and in consequence there is a severe strain on the pantograph in action.

Careful tests have been carried out with various pantograph pressures; the most satisfactory results obtained are with a total pressure of 23 lb. at the normal running

height of 16½ ft., giving 18 lb. at the minimum and 30 lb. at the maximum height.

A typical curve of these average set pressures showing the variation of pressure with elevation is given in Fig. 2(B). Lower pressures make for arcing, and higher pressures for increased wear on both the contact elements. This is invariably found to be the case with pantographs showing indications of sparking, and also when strips wear out before they have completed the desired mileage.

TABLE 2.

Pantograph Failures.

	From August 1928 to December 1929	1930	1931	1932	To August 1933
Structure wrecked or damaged through obstructions ..	5	5	3	8	0
Broken panel tubes	15	39	10	6	0
Defective pistons	11	6	2	2	1
Balancing gear, trays, pressures, etc.	3	4	3	2	1

Lubrication.

Graphite grease in collector trays has not been found entirely satisfactory. During the wet season the grease is blown from the trays and scattered all over the roof and coach ends, making conditions disagreeable for the ticket-examining staff, who get their uniforms soiled with the falling grease, when passing through the gangways between coaches. There is also the risk of the grease, in this state, being blown on to passengers on the platforms.

Water, having a deleterious effect on this grease through the solubility of its lime or soda soap content, impairs the lubrication, and hence excessive strip wear follows periods of heavy rainfall. In dry weather the grease becomes covered with a hard skin, which lacks adequate lubrication, and accounts for harsh running of the pantograph.

Encouraging results were obtained with a system of oil lubrication on the contact wire by using the steady arm tubes as oil reservoirs, and allowing the oil to feed through gradually.

The pneumatic grease-gun, illustrated in Fig. 2(c), has proved a most effective and satisfactory method of lubrication and has now been adopted for use on this system. Special grease is fed through a rubber tube (⅜-in. hole) from the gun to the centre of the pantograph collector tray, where it is forced through a $\frac{1}{16}$-in. orifice carried through a centre contact strip. An air pressure of between 15 and 25 lb. per sq. in., operating the gun, gives the required gradual feed of the lubricant, which is deposited on the contact wire through its wiping action over the strip. An electric cut-out valve, operated automatically by the master controller, is fitted in circuit with the air line to the gun so as to cut off the feed during the periods when the coach is standing in stations, thus only allowing a grease feed when the coach is in motion.

The contact wire is lubricated three or four times daily by this method, and this, in addition to the existing graphite grease in the trays, is sufficient for providing adequate lubrication. Four or five units fitted with the grease-gun apparatus are sufficient for the system.

Mobilgrease No. 2 is used in the grease guns, with satisfactory results; this product is semi-fluid at normal atmospheric temperature (75° F.), and "stringy" at all temperatures. It possesses the desired quality of adhesion to prevent any dripping; furthermore, it is not affected by moisture. The Mobilgrease forms a film over the graphite grease in the collector trays, which improves conditions with regard to the deleterious effect of water on this grease and prevents its surface hardening through exposure.

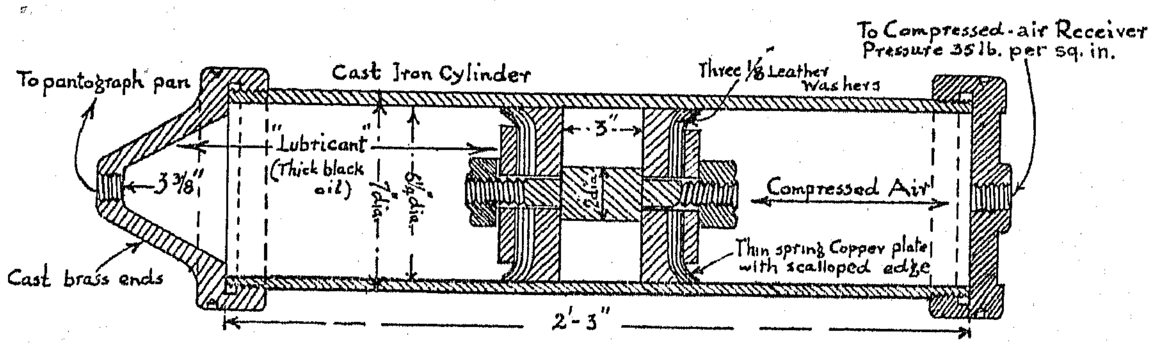


FIG. 2(C).—Pneumatic grease gun for lubricating overhead contact wire. (The grease gun is situated on the roof of the coach, and the lubricant is fed through a rubber tube into the pantograph skate pan.)

OVERHEAD TRACK EQUIPMENT.

The underslung suspension type of construction of the overhead-line work (using two 6-in. suspension insulators coupled in series) has proved satisfactory, particularly owing to its flexibility.

The catenary over the running tracks is 37/·115-in. hard-drawn copper wire, and in sidings 7/·144-in. silicon bronze is used. The contact wire is 0·25-sq. in.

solid hard-drawn grooved copper. Suspension droppers are placed 18 ft. 4 in. apart, and the catenary and contact are bonded at mid-span.

Table 3 shows the wear of contact wire over a period of 5 years to June, 1933. The average numbers of daily and monthly pantograph passings are also given.

Main Motors.

A motor-coach is equipped with four axle-hung motors, two being mounted on each bogie, and transmitting power to the wheels through the usual type of spur gearing. The output of a motor at the 1-hour rating is 187 h.p. at 225 amps., 700 volts, and provision is made for field tapping. The motors are connected in pairs, the two motors of a pair being permanently in series, each insulated for 1 500 volts to earth. The clearance between the under-side of a motor and the level of the track rails is 5 in. (with new tyres), and the height of the upper surface of a motor carcase above the level of the track rails is 39 in.

Ventilation.

The motors are self-ventilated by a fan on the armatures. This method of air circulation has not proved entirely satisfactory, owing to the large amount of dirt and dust drawn into the motors and deposited round and about the windings and brushgear, and which chokes the ventilating ducts through the armature core. This has resulted in a great deal of trouble with brushes, insulation, breakdowns, and flash-overs. To combat this dust nuisance, excessive maintenance work has to be constantly carried out.

When motors are so situated that they draw in the track dust and dirt which is stirred up by the passing train, enclosed ventilation is preferable. This may take the form of forced ventilation or a type of pipe ventilation, but in either case the air-supply ingress must be so situated as to reduce the amount of dust drawn in, or some form of air filter must be employed.

Brushgear.

The brushgear has given satisfaction, but a certain amount of trouble has been experienced with the brushes, through pronounced side wear, caused by sand and grit gaining access to the brush box, and settling into the space between the brush and the brush-box wall; thus producing a ledge and preventing the brush from following up wear and maintaining proper contact with the commutator.

From the "lightning" or "tree like" markings on the brush sides, it was thought at first that current was responsible for this peculiar side wear. As a result of careful observations, however, it was definitely established that the wear was caused through ingress of sand and grit. This trouble has not been overcome entirely, but marked improvements have been made by the cutting of slots in the side of the brushes, which affords an easy passage away of the sand and grit that enter the holder.

The brush dimensions are $2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{3}{4}$ in. The brushes are fitted with flexibles; the allowable wear is $1\frac{1}{2}$ in., the lever tension is 7 lb. with new brush $2\frac{1}{2}$ in. long and $4\frac{1}{2}$ lb. with worn brush 1 in. long, and the average mileage per $\frac{1}{2}$ in. wear is 40 000 miles.

Fields.

The field coils are insulated with micanite between turns and linen tape as an outside covering. A large number of failures have been experienced owing to loose coils fouling the motor cases, resulting in abrasion of the external insulation and earthing of the conductor.

As a result of investigation it was found that the spring plates had not sufficient tension for keeping the coils secure with the shrinkage of insulation, through

Table 3.

*Wear of Contact Wire.**

Section	Number of pantograph passings				Wear of original wire, top to bottom (in.)					
	Daily		Monthly		Up			Down		
	Up	Down	Up	Down	Maximum	Average	Minimum	Maximum	Average	Minimum
CT–SR	251	254	7 780	7 874	0·084	0·067	0·046	0·102	0·060	0·040
SR–CMT	242	239	7 500	7 409	0·075	0·055	0·039	0·074	0·057	0·046
CMT–WBG	206	206	6 386	6 386	0·055	0·047	0·038	0·059	0·049	0·039
WBG–RT	160	160	4 960	4 960	0·075	0·047	0·041	0·080	0·050	0·038
RT–FH	109	109	3 379	3 379	0·085	0·050	0·043	0·072	0·052	0·046
FH–ST	43		1 333		(Single-track) 0·056 (max.); 0·052 (average); 0·049 (min.).					

CT = Cape Town
SR = Salt River
CMT = Claremont

WBG = Wynberg
RT = Retreat
FH = Fish Hoek } Single track
Simonstown = ST }

* The original thickness of the wire was 0·585 in.

expansion and contraction. To overcome the trouble all coils have been re-insulated externally, the additiona insulation being inserted between the coil and motor frame, and the spring plates have been reset and re-tempered to enable them to withstand additional tension

Cable.

The field-coil interconnector and motor cables are rubber-insulated; these cables have given a certain amount of trouble through the rubber perishing and cracking, resulting in breakdowns to earth; it is probable that this is due to ionization. Rockbestos A.V.C. insulated cable is being introduced to overcome the trouble.

Armatures.

Metallic dust and moisture have been responsible for the majority of armature failures. Through expansion and contraction and centrifugal strain, the original binders slackened badly, and the moist saline atmosphere along the coastal sections penetrated the tinning, causing rust and corrosion of the steel binding wire. The metallic dust has been especially harmful, working its way into the minute cracks and crevices and resulting in ultimate breakdowns on various occasions. To overcome this, as far as possible, a thorough and rigid programme of maintenance has had to be adhered to. This includes re-banding, using a heavier-gauge wire and giving special attention to the "canvas hoods," which go a long way towards protecting the windings, as well as dipping of the armatures in varnish and baking, which is effected every 100 000 to 150 000 miles.

It may be mentioned that some brands of varnish used have not given satisfactory results. These, although reputed to have special qualities for traction work, have not performed as predicted when put into use. This particularly applies to golden varnishes.

Commutation has been satisfactory, the average wear being 0·006 in. per 100 000 miles.

Auxiliary Machines.

Apart from a little trouble during the early days of running, which was overcome by increasing the permanent resistance, on the negative side of the motor-generator set, from 10 ohms to 15 ohms, these machines have operated entirely satisfactorily.

Reavell's Rotary Exhausters.

The capacity of an exhauster when operated at full speed is sufficient to produce in 10 sec. a vacuum equivalent to 20 in. of mercury in a container of 12 cub. ft. capacity, against a leak to atmosphere through a $\frac{3}{16}$-in. diameter hole. When operated at reduced speed an exhauster is capable of maintaining this vacuum against the same leak. Each machine is equipped with an adjustable safety valve ("snifter" valve). The continuous-running speed is 1 400 r.p.m., and high speed 1 650 r.p.m.

A great number of exhauster failures were experienced at first, through several causes, and since their elimination satisfactory operation has been maintained. The following were the chief troubles experienced.

(1) *Snifter valves.*—These were mounted direct on the machine, and gave trouble through ingress of dirt and dust causing the valves to stick. The trouble was overcome by introducing a pipe connection and mounting the valve inside the coach interior away from the dusty surroundings.

(2) *Leaking glands* caused interruptions of the oil feed, resulting in overheating and seizure of the machines. This trouble was eliminated by enclosing the lubricator-pump plunger in an airtight cover, which rendered the gland secure against leaks. The machine glands were fitted with grease cups and kept well lubricated, thus minimizing their wear and consequent leaks.

(3) *Lubricator ball valves* sticking through ingress of foreign matter, such as small pieces of fibrous substance, which found its way into the oil sump by feeding through with the oil. This fault caused a run-through of oil which quickly exhausted the supply, resulting in seizure of the machine. A small cylindrical-shape filter, made of fine-mesh wire gauze, fitted to the oil passage leading to lubricator, inside the sump, mastered the trouble.

A great deal has been accomplished through the systematic overhaul of these machines, which is effected at every 15 000 coach miles; and through the experience gained it has been established that to overrun an exhauster without these periodical cleanings of the rotary parts invites trouble.

The following is the record of exhauster failures from 1929 to 1933: 1929, 35; 1930, 14; 1931, 5; 1932, 6; 1933, 2.

Fuses.

1 500-volt Equipment.

Main and auxiliary fuses of 1 000-ampere and 65-ampere ratings were provided and housed in a special fuse box, situated on the roof of the coach.

After the second year of operation, trouble was experienced with the main fuses blowing for no apparent cause, and it could only be assumed that the failures were due to deterioration of the fuse through a series of overloads, such as flash-overs on the motors and resistances. The difficulty was remedied by dispensing with the main fuse entirely, and depending on the main circuit-breakers for the protection of the equipment.

A few cases of the auxiliary fuses blowing in the same manner have occurred; if these continue a complete replacement will be effected.

110-volt Circuits.

The control and lighting fuses are of the self-indicating enclosed (cartridge) type, of 30-ampere and 15-ampere rating respectively.

A lot of trouble was experienced with the "control" fuses blowing owing to deterioration through overloads; also the indication labels on these fuses, which were gummed to the cartridges, became detached and lost. In some cases the printing on the label became obliterated, resulting in "lighting" fuses being put into the "control" circuit, and vice versa. Frequently the drivers, after replacing fuses blown on an intermittent fault or short-circuit which cleared itself, gave the wrong coach number when reporting the trouble, resulting in, at times, a recurrence through the wrong coach receiving the necessary attention.

All this was overcome by substituting for the (control fuse) cartridge tube between the metal caps a glass tube, without asbestos filling, and gumming inside the tube a label giving the coach number. This modification renders the fuse wire always visible for inspection, and consequently there have beeen no mistakes with wrong coach numbers of blown fuses.

Gears and Pinions.

The first problem encountered in connection with gear wear, on this system, was brought about through bad riding qualities of the coaches, due to excessive lateral movement, which reacted badly on the motors and their suspension bearings. Consequently the gears suffered through bad meshing. This trouble was eventually overcome by modifying the " spring centring device " controlling the lateral movement (see page 590).

The above condition led to the motor suspension bearings becoming loose through their keep bolts slackening, resulting in bad wear in the bore of the bearing and damage to the outside of the brass, where it is held in position. Thrust faces also became excessively worn and damaged owing to the pounding they received. This resulted in a degree of incorrect meshing due to gear spread, and set up considerable vibration, resulting in pronounced wear at the ends of the teeth. The additional strain loosened the gearcase bolts, allowing the lubricant to escape freely from between the joints and further increasing the wear on the gears themselves. In some cases armature-bearing housings slackened in the motor frame.

This early experience demonstrated the disastrous consequences resulting from improperly meshed gears, and the importance of maintaining the correct centre-to-centre distance between the pinion and the gear wheel. With this in view, the clearances of new bearings were reduced—armature pinion-end bearings from 0·012 to 0·006 in., and suspension bearings from 0·015 to 0·008 in. The scrapping limit was reduced from 0·030 to 0·025 in.

Gearcases.

Gearcases have given rise to a great deal of trouble through the two halves not fitting tightly at the split, resulting in ingress of dust and dirt, as well as escape of grease through the joints. The insertion of wool (plaited) between the joints has greatly improved conditions.

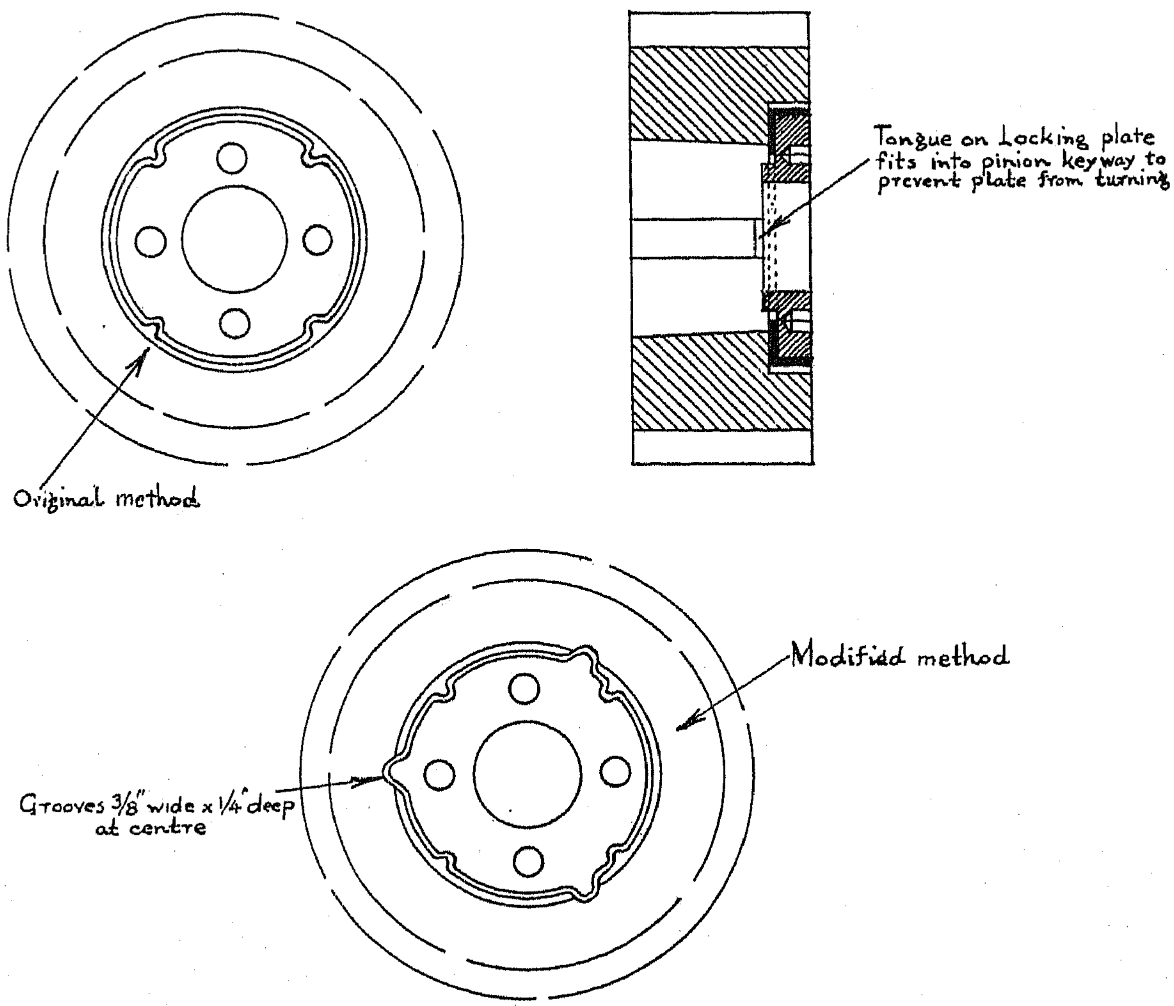


Fig. 3.—Main motor pinion locking-plate and nut.

Pinion-Nut Locking Plates.

Fig. 3 illustrates a modification of the pinion-nut locking-plate. With the original method a projection from the locking plate fitted into the pinion keyway to prevent the plate from turning. In many instances this tongue broke away when the nut was tightened, resulting in the nut slackening off, destroying the thread on the armature shaft, and damaging the gearcase. Fortunately no pinions moved from their seatings through this defect. To overcome the trouble three grooves have been ground in the pinion at an angle of 45° to the edge, and the plate is bent over into these grooves after the nut has been tightened. This treatment has proved effective.

Tooth Wear.

The wear permissible on gearwheel and pinion teeth before their rejection is taken as one-third of the original thickness of new teeth at the pitch circle. This gives a maximum backlash of 0·409 in. between the teeth. The figure was arrived at after careful observations had been made as to the nature of the wear and of the noise arising from backlash. Gauges are used for determining the stage at which gears and pinions should be scrapped. A certain amount of discretion, however, has to be exercised owing to the variety of tooth shapes, due to wear, as it sometimes happens that the nature of the tooth wear warrants the discarding of the pinion or gearwheel before the wear at the pitch circle is down to the limiting gauge.

After 2 years' service the average rate of wear per 100 000 miles on gearwheel teeth measured 0·022 in. on the tooth face at the pitch circle. Pinions were being discarded for tooth wear at 108 000 miles. Prolonged investigation proved that the grade of lubricant used was mainly responsible for the rapid rate of tooth wear.

Lubrication.

After gearcases have received an initial fill of grease they are topped up at weekly intervals, when the trains come into the shed for inspection. The average mileage between inspections is approximately 1 500 miles. Fig. 4 illustrates the grease consumption for gears, in miles per lb., over a period of 5 years' operation. The particulars of the various grades of grease employed are as follows:—

HT2 grease (maker's original recommendation).—This is a special lime-base bearing grease, designed for high-temperature conditions where pressures are heavy, the oil content consisting of high-grade steam-cylinder oil. The physical characteristics are as follows: melting point, 205° F.; lime-soap content, 20 per cent; water content (maximum), 2 per cent; mineral-oil content, 78 per cent; initial fill of gearcases, 20 lb. per case; weekly topping, 4 lb. per case.

This grease thinned out considerably, owing to violent churning, when diluted with oil which seeped through from the armature bearings, and by the high temperature developed. This caused large leakage through the casing joints, resulting in heavy consumption and poor lubrication.

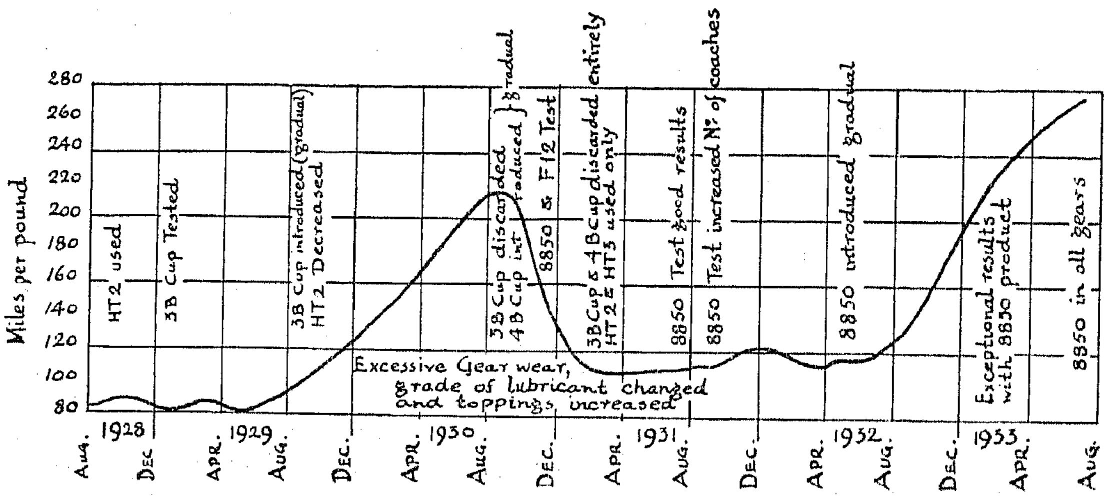


FIG. 4.—Oil-consumption curve for main motor pinions and gear wheels.

The improvement with the lubricant now in use, after the gearcase trouble had been remedied, reflects as follows:—Gearwheel teeth, average rate of wear per 100 000 miles measures 0·005 in. on the tooth face at the pitch circle, against 0·022 in. previously quoted. The average rate of wear of pinion teeth is 0·015 in.

Broken Teeth.

The average mileage of pinions discarded with broken teeth is 103 000 miles, and of gearwheels 185 000 miles. All breakages have taken place along the root of the tooth. The nature of the fractures has led to the belief that they are caused by impact and not fatigue. The impact can be given during shunting operations, if the driver throws his reverser and applies reverse power while the train is still moving in the forward direction. To prevent this misuse of the motors, a modification is being made which renders it necessary for the driver to leave his driving position before he can throw the reverser. This entails a separate switch, mounted away from the driving position and operated by the master-controller reversing handle, which ensures that the driver brings his train to a standstill before applying reverse power.

3B cup grease.—This is a general-service lime-base cup grease of "buttery" structure, having the following characteristics: melting point, 200° F.; lime-soap content, 25 per cent; water content (maximum), 2 per cent; mineral-oil content, 73 per cent; initial fill of gearcases, 20 lb. per case; weekly topping, 2¾ lb. per case. This grease gave a lower consumption than HT2, but separated out into oil (which was lost) and a dry soap residuum which had little, if any, lubricating value.

4B cup grease.—This grease is of exactly similar structure to 3B cup grease, but is of heavier consistency owing to lower oil content. It has the following characteristics: melting point, 205° F.; lime-soap content, 30 per cent; water content (maximum), 2 per cent; mineral oil content, 68 per cent.

In an endeavour to prevent oil separation and to enable the grease better to withstand the effect of high temperature, this grade was used to top up the cases originally filled with 3B cup grease, but without improvement. This mixture gave no better lubrication, and provided additional dry soap-like residuum. A

sample of this substance was submitted to analysis and reported on as follows:—

"(1) It contained 8 per cent more oil of the nature of armature bearing oil.
(2) It contained 7 per cent of carbonaceous matter and free carbon.
(3) It contained oleate of iron corresponding to 2·7 per cent of oxide.
(4) There were chips of metallic iron present, amounting to 0·11 per cent.
(5) Free silica, as powder and grains of quartz, 0·28 per cent.
(6) Almost no moisture or other matter volatile at 220° F.
(7) The flakes of steel measured up to 1·5 mm in diameter, and the fragments of quartz present up to 1 mm.
(8) The material had a considerably lower lubricating value than the original grease.
(9) It also behaved differently against the various solvents tried."

From these observations the following conclusion was drawn:—

"(1) The quartz grains which had found access to the grease produced an abrasion of particles of steel, some of the particles being as fine as dust, others larger.
(2) This process developed heat, causing carbonization of the fatty acids and at the same time splitting of some of the fat.
(3) The fatty acids thus liberated combined with the iron dust and formed oleate of iron, which is not viscous but tough, thus reducing the lubricating power of the remaining grease still further and consequently increasing the trouble."

At this period excessive wear of gear teeth was experienced, which made imperative (*a*) a more suitable lubricant, and (*b*) improvements in the gearcase joints to minimize the ingress of dirt and dust, and prevent loss of lubricant.

*HT*3 *grease.*—This grease has similar structure and characteristics to HT2, but is of stiffer consistency, and it was hoped that its superior heat-resisting qualities would solve the problem. Better results were obtained with an initial fill of 20 lb. per gearcase and a weekly replenishment of 3 lb. per case, but thinning-out very similar to that encountered with HT2 was experienced, and under the heavy pressure and impact conditions this grease did not satisfactorily protect the tooth surfaces of the gears from wear.

Product 8 850.—This is a highly viscous black residual oil having the property of great adhesiveness, in addition to the following characteristics: specific gravity, 1·01; pour point, 90 per cent; flash point, 540° F.; staybolt viscosity at 210° F., 2 000 to 2 500 sec.; initial fill, 8 lb. per gearcase; weekly topping, 1 lb. per gearcase (winter) and $1\frac{1}{2}$ lb. per gearcase (summer).

Although the use of this grade of gear oil was originally considered, it was feared that its glutinous nature would give trouble due to cross-leakage into the waste-packed armature bearings; but, although it has been found in practice that this cross-leakage does occur to a small extent, this product's entire solubility in the bearing oil renders this occurrence quite innocuous to the bearings and the syphoning qualities of the wool.

Product 8 850 has proved itself the most satisfactory lubricant used to date in protecting the working surfaces of gear teeth and, consequently, in reducing wear. It adheres to the tooth surfaces tenaciously, thus preventing metallic contact to the maximum, and its cushioning effect secures less noisy operation. The latter feature has been a big improvement over the greases previously used.

Technical Data concerning Gear Wheels and Pinions.

(1) Gear-wheel rims are of chrome nickel steel, heat treated before machining, having an ultimate tensile strength of not less than 50–55 tons per sq. in., and shrunk on to cast steel centres. The Brinell hardness on the surface of the teeth after machining is within the range 220–260.

(2) Pinions are of nickel-chrome steel alloy made by the acid, open hearth, or electrical process, and forged by up-ending to ensure that the grain is not parallel to the axis. The metal has an ultimate tensile strength, after heat treatment, of 40–50 tons per sq. in. The Brinell hardness on the surface of the teeth after machining is within the range 400–450.

(3) Gear wheel: 72 teeth; "Maag" form of tooth, with $2\frac{1}{2}$ in. diameter pitch. Pinion: 23 teeth, "Maag" form of tooth, with $2\frac{1}{2}$-in. diameter pitch; width of teeth, 3·94 in.

(4) Gear-wheel teeth: standard thickness at pitch circle is 0·5769 in. Pinion-wheel teeth: standard thickness at pitch circle is 0·6802 in.

(5) Backlash between gear wheel and pinion teeth is from 0·012 to 0·022 in. (must not be less than 0·010 in.).

(6) Scrapping size: when teeth are two-thirds of their original size at pitch circle (gear-wheel teeth 0·391 in., pinion teeth 0·469 in.).

(7) Wheels are 40 in. diameter, running on 80-lb. rails, gauge of track 3 ft. 6 in.

(8) Maximum speed on stopping train, 45 m.p.h. Average number of stops and starts, 1 per mile. The motor-coaches have collectively covered 12 866 000 miles in 48 months.

MAIN-MOTOR ARMATURES AND SUSPENSION BEARINGS.

A great deal of attention has been given to the maintenance and upkeep of main motor armature and suspension bearings on this system, particularly with regard to their lubrication, from which satisfactory results have been achieved.

Fig. 5 shows oil-consumption curves over a period of 5 years' operation. At first a low oil consumption was aimed at, and later—as a result of experimenting to make sure that the critical oil lift of 2 in. was not exceeded and normal temperatures were maintained after heavy service, especially at the end of the oiling period—the oil level was lowered, with better results as regards consumption and with no abnormal wear detected during

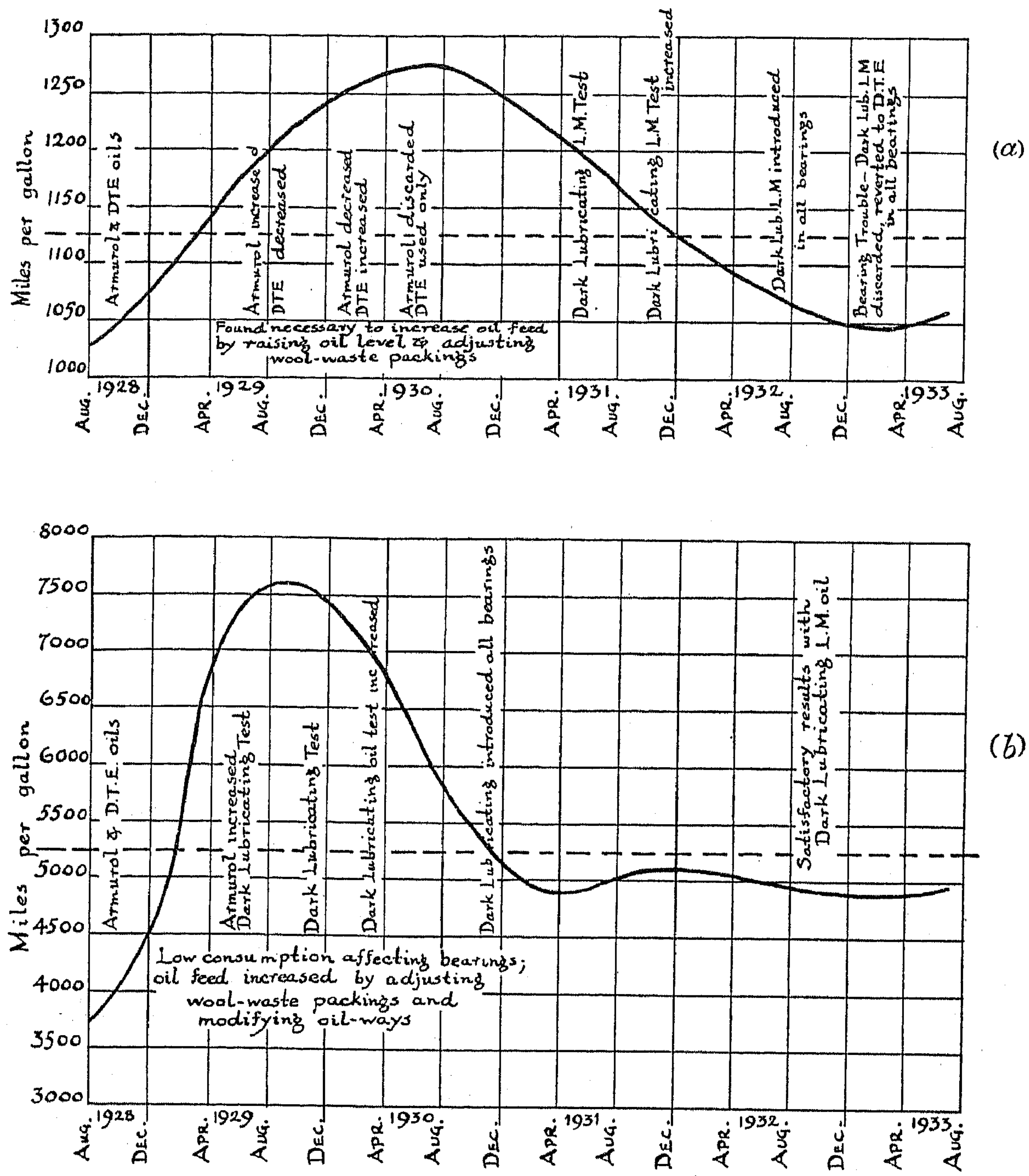


FIG. 5.—Motor-coach oil-consumption curves.

(a) Main motor armature bearings.
(b) Main motor suspension bearings.

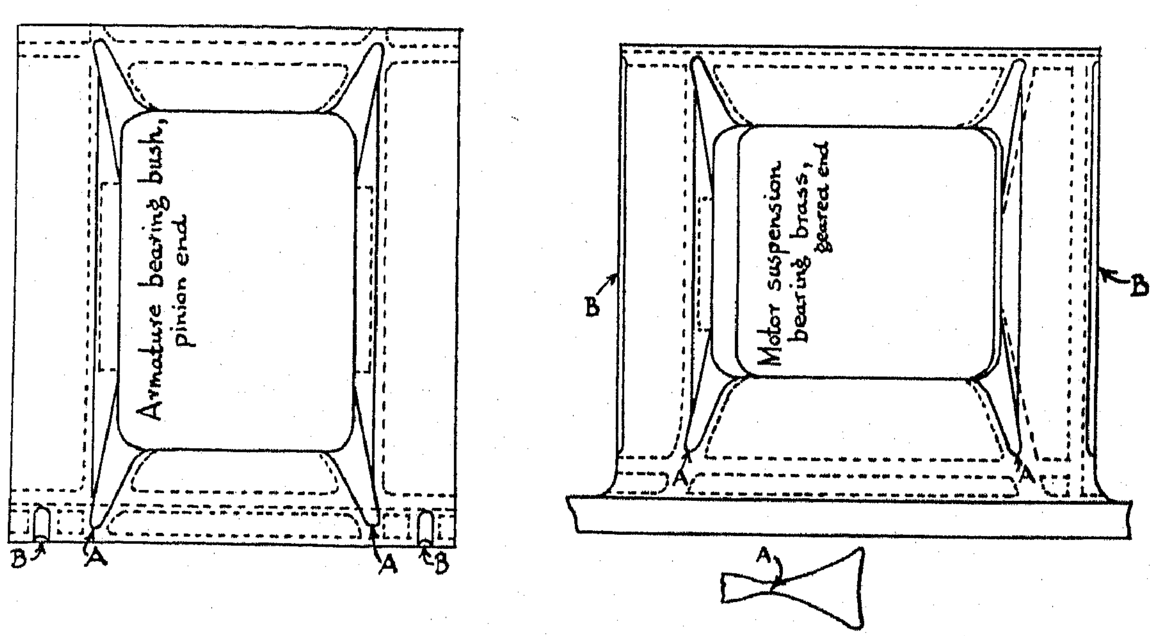


FIG. 6.—Main motor armature and suspension bearings.

examination of bearings. Later it was found that on certain types of coaches, which were used on intermittent service, the period between oilings could be extended with no ill effects. This practice, however, was proved wrong in that a higher safety margin was found to be necessary on examination of these bearings in the course of periodical overhaul, after about 18 months' service (their second inspection). It was found that abnormal wear had taken place in many cases, especially towards the thrust ends and on the thrust faces. In some instances the babbitt was found cracked or dragged, indicating that overheating had taken place at some time or other; during this investigation it was also found that the wool-waste packing had not been packed tightly enough in some of the corners of the windows.

The experience gained and conclusion arrived at are that a higher margin of safety must be allowed with regard to oil consumption, in order to overcome the many small discrepancies that it would be impossible to eliminate entirely; an average oil consumption giving the best all-round results was also attained; this is shown by the dotted lines in Fig. 5.

Fig. 6 illustrates the developed view of oil grooves in armature and suspension bearings. It was found necessary to modify slightly the grooves on the commutator-end armature bearings and the suspension bearings, as shown in Fig. 6, in order to increase the oil flow to the thrust faces, which were not receiving an adequate supply, with the result that excessive wear was being set up. With the pinion-end armature bearing this was not found necessary. In Fig. 6, A represents the oilway, and B the chamfer at the joint. A fishtail spillway (see lower sketch) extends from the end of the oilways A round the thrust face: this spillway is approximately $\frac{1}{32}$ in. deep at one end and tapers off to nothing at the other. A and B are linked together at the thrust end of the commutator-end bearing bush by means of a groove $\frac{1}{8}$ in. wide by $\frac{3}{32}$ in. deep.

Of the number of oils tested, "DTE" extra-heavy oil has given the most satisfactory results in armature bearings, and a dark lubricating oil, which is a lower-grade oil, has proved successful in suspension bearings; these two oils are used throughout the year, without changing to winter or summer grades. The physical characteristics of these oils are shown in Table 4.

With a view to economy, "dark lubricating oil," which is a cheaper grade, was tried out in armature bearings, and in consequence of the satisfactory results it gave during tests, which extended over a period of 12 months, a decision was made to lubricate all bearings with this oil. Its introduction, however, was followed by an epidemic of bearing trouble, which resulted in a speedy reversion to the higher-grade oil.

The experience gained on this system has established the following points regarding the maintenance and upkeep of armature and suspension bearings:—

Oil.—To provide an efficient load-carrying oil film the use of a high-grade heavy-bodied straight mineral oil, which has good oiliness or lubricating value, is necessary for armature bearings. Suspension bearings can be successfully served with a lower-grade oil of somewhat similar body.

Oil supply.—It is necessary to maintain an adequate oil supply, as a safeguard against rupture of the oil film through a lean feed, which will result in increased friction and wear. The oil lift must therefore be maintained well within the critical value, to provide for any small discrepancies should abnormal conditions develop.

Wool waste.—High-grade, long-fibre wool with good resiliency has been proved the only reliable product. Wool with a poor degree of resilience has been found quite unsuitable, as it loses capillary value and its surface tension on the journal, and also glazes on the contact area.

Packing.—Of the various methods of packing tried, the best results have been achieved with the wool cut up into lengths of 9 in., and before the prepared wool is inserted into the waste chamber a small quantity of oil is placed in the well. With this method the wool waste is packed in a soaked condition, when it loses its elasticity and can be packed more tightly than when only damp.

It is found essential for the packer to distribute the wool into the various parts of the chamber by hand,

TABLE 4.

	Armature bearings	Suspension bearings
Specific gravity at 60° F. . .	0·895	0·930
Cold test at which oil becomes sluggish	20° F.	10° F.
Flash point	420° F.	280° F.
Viscosities. Redwood (sec.)		
at 70° F.	1 540	1 900
at 100° F.	525	550
at 130° F.	210	212
at 140° F.	175	173
at 200° F.	64	60
at 210° F.	58	55

and to see that the window is properly filled, to ensure a continuous tight seal of this area.

All bearings are "run in" after packing before assembly of motors into their trucks, as during this initial run faults are often discovered which cause overheating. For the first 2 weeks in service, bearings are run with a higher oil level; after the ramming-down of the packing at this period the bearing does not receive further attention until heavy inspection or overhaul, after it has run 60 000 miles. Only in exceptional cases are bearings repacked with the coach superstructure in place, as under these conditions it is found that the cramped space available makes it practically impossible to pack a bearing properly.

The subject of lubrication has been dealt with fairly extensively in this paper, as the realization that it plays a very important part in securing economical operation led to the collection of extensive statistics that have been proved valuable and illuminating.

When it was found that the maintenance costs, and the interruption of the smooth running of the service, increased almost in direct proportion to the efforts made towards reducing oil consumption, experiments were instituted to decide the most economical mean between

these two factors. The result of these experiments is represented by the dotted lines in Fig. 5, which allow for a consumption of oil that to some engineers may seem extravagant, but which has proved to be the most economical amount.

The quality and type of oils most suited to the operating conditions have also received much study. It has been established that good results secured with oils during test runs did not necessarily prove their suitability under working conditions. During tests the marked units inevitably receive careful attention from operators who are working under direct supervision, which practically eliminates the human element and the abnormal occurrences that are bound to happen occasionally in everyday routine. To meet such peak emergencies a sufficiently high margin of safety must be provided, and the oil which can be relied on to furnish these results is the most economical, even if costing slightly more in the first instance. This quality can only be disclosed by extended service conditions. The failure of "dark lubricating oil" in armature bearings, despite successful tests, illustrates this point.

Table 5 gives a summary of the bearing failures covering the 5 years from August, 1928, to July, 1933.

Table 6 shows the monthly return for July, 1933; it is a typical specimen.

TABLE 5.

Armature-Bearing Failures: Hot Bearings (all pinion end), August, 1928, to July, 1933.

	1928	1929	1930	1931	1932	1933	Totals
Cause unknown	1	–	–	–	2	–	3
Suspected wool-waste packing ..	–	–	1	–	1	–	2
Fractured casting, leaking oil ..	–	–	–	–	5	–	5
Suspected defective babbitt	–	–	1	1	1	–	3
Unsuitable oil (" dark lubricating ") ..	–	–	–	–	2	3	5
Totals	1	0	2	1	11	3	18
Annual motor-coach mileage	1 447 379	2 704 463	2 505 577	2 486 375	2 363 970	1 357 627	12 865 391

BOGIES AND WHEELS.

Side Control.

During the first 2 years of operation a great deal of trouble was experienced with the rough riding of motor-coaches, the cause of which was traced to the "spring centring device" controlling side play. This condition reacted badly on the equipment, particularly the main motors, wheels, and pantographs.

During a prolonged investigation many modifications and adjustments were effected, which improved conditions, but it was not until the entire removal of the "spring centring device," which left the bogies free to play transversely without the control of the compression of the spring device, that satisfactory results were obtained in eliminating the excessive side sway and rocking movement of the coaches. As the result of this experiment the modification was extended gradually to all the motor-coaches.

Axle End-thrust Bearings.

These bearings, which are illustrated in Fig. 7, have been tried out with satisfactory results in reducing wear and tear, particularly wheel-flange wear. Originally the total side play of the wheel in relation to the centre line of the coach was $\frac{1}{2}$ in. The free movement (initially $\frac{1}{2}$ in.) set up by the wheel flange striking the rail caused excessive end wear on the axle-box brasses and oscillation of the motors. The fitting of an end thrust so that the axle could only oscillate $\frac{1}{32}$ in. per side in the box, effected control over this side play, as the wheel flange striking the rail could only be carried through the box by this small distance. This reduced the shock considerably, as the axle could not gain the momentum hitherto experienced; the end play with the end-thrust bearing is $\frac{5}{32}$ in. per side, or a total of $\frac{5}{16}$ in. [see Fig. 7(*c*)]

Reducing the end play in the bearing would have the same effect if the area of the end of the bearing were large enough to withstand the strain. As this was not the case, the end thrust was introduced in the axle-box cover, which had the necessary area. With the wheels controlled laterally in this manner, flange wear is not so rapid, because the flanges are not permitted to follow their own course and oscillate rapidly from side to side.

Wheel Wear.

Normally, wheels are only removed for tyre-turning when the coaches come in for heavy inspection or overhaul, after completing between 50 000 and 70 000 miles' service. The average thickness of flanges at this period is between $\frac{7}{8}$ in. and 1 in. at the gauging point, the minimum thickness allowed being $\frac{3}{4}$ in. The wear on the tread is more severe, the average value being between $\frac{3}{16}$ in. and $\frac{7}{32}$ in. This is within $\frac{1}{32}$ in. of the limit gauge, the permissible wear on the tread being $\frac{1}{4}$ in.

The general dimensions of wheels and tyres are as follows: maximum diameter of wheel, 40 in.; maximum thickness of tyre, $3\frac{3}{4}$ in.; minimum diameter of wheel,

TABLE 6.

Typical Monthly Report of Lubricants for July, 1933.

Service, and lubricant used	Amount of lubricant used: Operation	Amount of lubricant used: Repairs, etc.	Amount of lubricant used: Total	Lubricant recovered*	Total lubricant used	Price per gallon or per lb.	Value of lubricant (£ s. d.)	Cost over 1 000 motor-coach-miles of operation: Current month	Cost over 1 000 motor-coach-miles of operation: Previous month
Main motor armature bearings:—									
Armature bearings: high-grade extra-heavy red oil	181 gal.	16 gal.	197 gal.	—	197 gal.	3s. 10d.	37 15 2	4s.	4s. 2d.
Suspension bearings: dark lubricating oil	$33\frac{1}{2}$ gal.	15 gal.	$48\frac{1}{2}$ gal.	—	$48\frac{1}{2}$ gal.	2s. $2\frac{1}{2}$d.	5 7 1		
Gears: black residual oil	665 gal.	140 gal.	805 gal.	—	805 gal.	$4\frac{1}{8}$d.	13 16 9	1s. 2d.	1s. 4d.
Exhausters: mixture, compound and mineral-red oil	$96\frac{1}{4}$ gal.	6 gal.	$102\frac{1}{4}$ gal.	—	$102\frac{1}{4}$ gal.	3s. $10\frac{7}{8}$d.	19 19 5	1s. 11d.	1s. 11d.
Axle-boxes: dark lubricating oil	$107\frac{1}{2}$ gal.	15 gal.	$122\frac{1}{2}$ gal.	—	$122\frac{1}{2}$ gal.	$9\frac{4}{5}$d.	5 0 1	5·5d.	4d.
Camshaft and pantograph grease cups: grease . .	3 lb.	—	3 lb.	—	3 lb.	9d.	2 3	—	—
M.G. and exhauster bearings: grease	7 lb.	7 lb.	14 lb.	—	14 lb.	$9\frac{1}{2}$d.	11 1	0·3d.	0·3d.
Pantograph skate pans: graphite grease	63 lb.	18 lb.	81 lb.	—	81 lb.	6d.	2 0 6	2d.	2d.
						Total . .	84 12 4		

Comparative Figures.

	July, 1933	June, 1933
Total mileage	191 587	188 293
Total value of lubricant: Operation	£74 19s. 6d.	£75 13s. 9d.
Total value of lubricant: Repairs	£9 12s. 10d.	£7 4s. 11d.
Total mileage per gallon: Armature bearings	1 058	996
Total mileage per gallon: Suspension bearings	5 718	5 793
Total mileage per lb.; Gears	267·9	256·8
Total cost per 1 000 motor-coach miles; Operation	7s. 10d.	8s.

* No lubricants purified this month: De Laval separator being overhauled and awaiting spare parts.

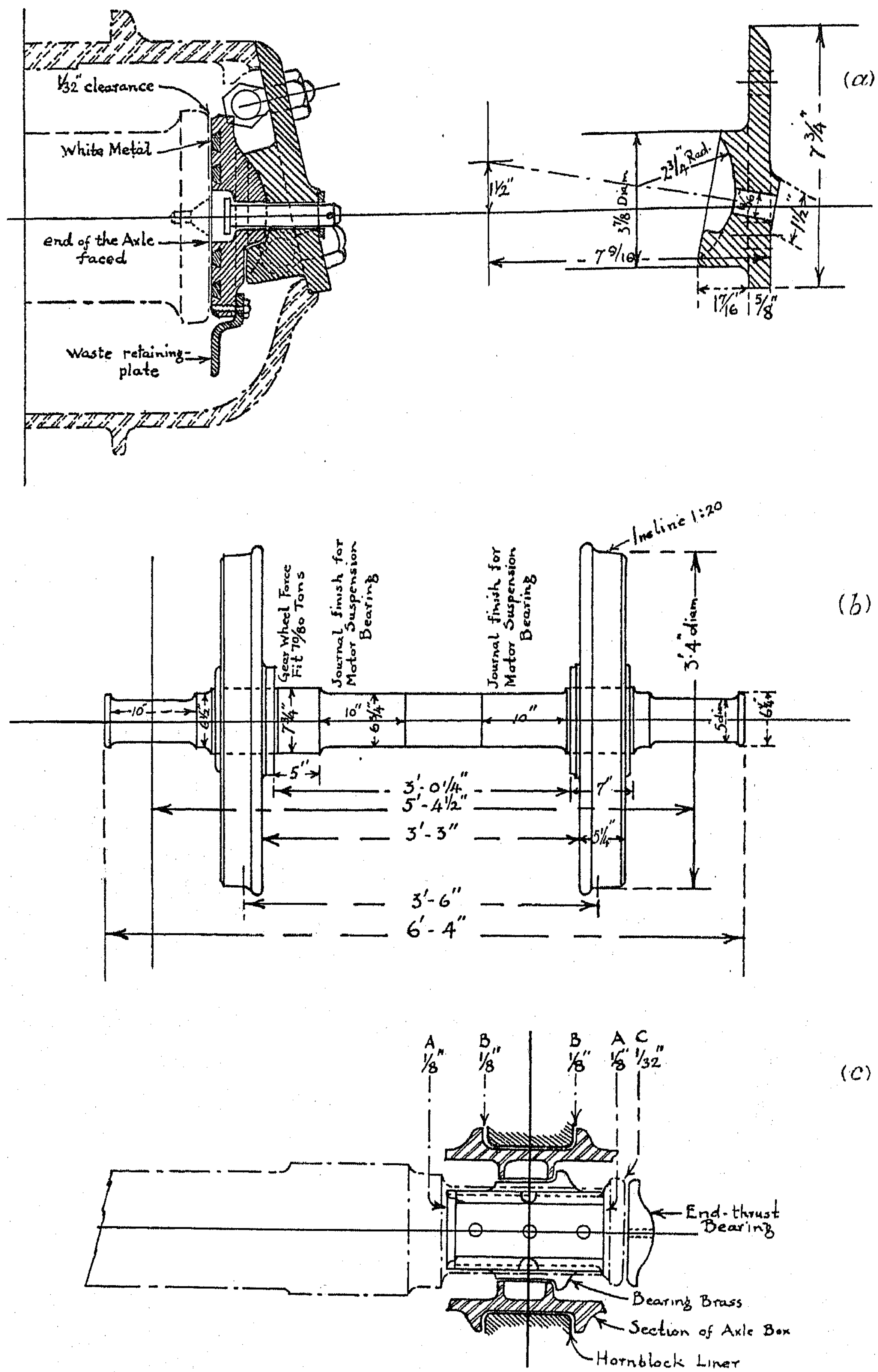


FIG. 7.

(*a*) Axle end-thrust bearing fitted to motor-coach axle box.
(*b*) Motor-coach wheels and axle.
(*c*) Total side play of wheel in relation to centre line of coach, before fitting of end thrust to boxes $\} = A + A + B + B = \frac{1}{2}$ in.
Total side play with end thrust fitted $= (C \times 2) + B + B = \frac{5}{16}$ in.

$35\frac{1}{2}$ in.; minimum thickness of tyre, $1\frac{1}{2}$ in.; maximum thickness of flange at gauging point, $1\frac{1}{8}$ in.; minimum thickness of flange at gauging point, $\frac{3}{4}$ in.; permissible flange wear, $\frac{3}{8}$ in.; average mileage between turnings, 60 000; minimum depth of flange to gauging point on tread, $1\frac{1}{8}$ in.; average cut at turning, $\frac{5}{8}$ in.; maximum depth of flange to gauging point on tread, $1\frac{3}{8}$ in.; average mileage between retyring, 250 000; permissible wear on tread, $\frac{1}{4}$ in.

Before the removal of the "spring centring device," which is mentioned above, rapid flange wear was experienced. Under the original conditions, flanges wore down at an acute angle, which necessitated an average cut of $\frac{3}{4}$ in. during wheel-turning, lessening the life of the wheel tyres considerably. By the removal of the "spring centring device" together with the fitting of "axle end-thrust bearings," abnormal flange wear has been overcome.

Brake Adjustments.

Failure of automatic slack adjusters resulted in a great deal of brake trouble. The automatic compensator for taking up the shoe wear being ineffective, brake pistons stuck owing to their extended travel as the shoes wore down. This resulted in wheels skidding, and in frequent intermediate hand adjustments being made between inspection periods. The trouble is being overcome by increasing the number of teeth in the ratchet wheel of the slack adjuster, which gives it a quicker action, allowing the shoe wear to be compensated automatically.

Axles.

Careful attention is being given to axles with regard to examinations and tests for flaws, cracks, and fatiguing. The maximum mileage of single axles up to the present is 270 000 miles. After axles have completed 200 000, 250 000, 300 000, and 350 000 miles respectively, one will be taken for test, the wheels pressed off, and a thorough examination made. No defects have been found on the axles examined hitherto.

Brake-shoe Dust.

The ingress of dirt and dust into the main motors has been mentioned, and it is interesting to note that the total weight of metal worn off the brake blocks per week by the 19 sets in service is as much as 7 610 lb.

Records.

Since the inception of electrification, full records have been kept of the troubles and work on the various items of the equipment. The careful compilation and the subsequent analsyis of these have proved them to be of inestimable value in assisting towards the successful running of the stock and guarding against failures. By some engineers, no doubt, the time spent in compiling data for records is begrudged, but under the stress of modern transport difficulties, every aid to success is welcome. The author is convinced from experience on this electrification scheme that adequate records, and the intelligent use of them, have played no little part in attaining the smooth and economical running of the service.

Acknowledgment.

The author would like to express to the South African Railways and Harbours Administration his thanks for their kind permission to publish the figures given in this paper.

DISCUSSION ON "THE THERMAL RESISTANCE AND CURRENT-CARRYING CAPACITY OF THREE-CORE SCREENED AND S.L.-TYPE CABLES."*

Mr. J. K. Webb (*communicated*): Considering the extent to which H-type cables are now used, it is rather surprising that this is the first description in this country of a method of computing their thermal resistances. Although some very good résumés have been given dealing with the calculation of thermal ratings of various cables, both the H type and the S.L. type are invariably overlooked.

As mentioned by the author, Simons's formula has been employed extensively in America, where it is standard practice to use a 3-mil copper foil. The formula quoted, however, is not strictly that given by Simons, which, using the author's symbols, should read:—

$$\frac{1}{S} = 6\sqrt{\left[\frac{t_s}{R\rho K \log_e (R/r)}\right]} \tanh 2\cdot 88\sqrt{\left[\frac{R\rho}{t_s K \log_e (R/r)}\right]} + \frac{1\cdot 56}{K \log_e (R/r)} \text{ thermal mhos per cm.}$$

In this form a close approximation is obtained when applied to H-type cables with 3-mil copper foil, but it is badly out when applied to cables with thinner aluminium foil.

The method of Beavis, although ingenious, is very cumbersome for application to specific cases, and cable designers will appreciate any more direct method involving less calculation.

It is a common belief, evidently shared by the author, that the thickness of the aluminium foil used on an H-type cable is 1·5 mils. This dimension, if taken from micrometer readings, may be merely nominal. Some time ago I measured some batches of this foil as received from manufacturers. The best method is first to remove the paper backing by soaking a fairly large sheet in water and deducing the thickness from the weight and density of a known area. Surprisingly enough, the thickness turned out to be considerably less than 1·5 mils, some samples being as low as 0·5 mil. Micrometer measurements are very misleading, since the foil is roughened to make it adhere to the paper backing and it is also perforated.

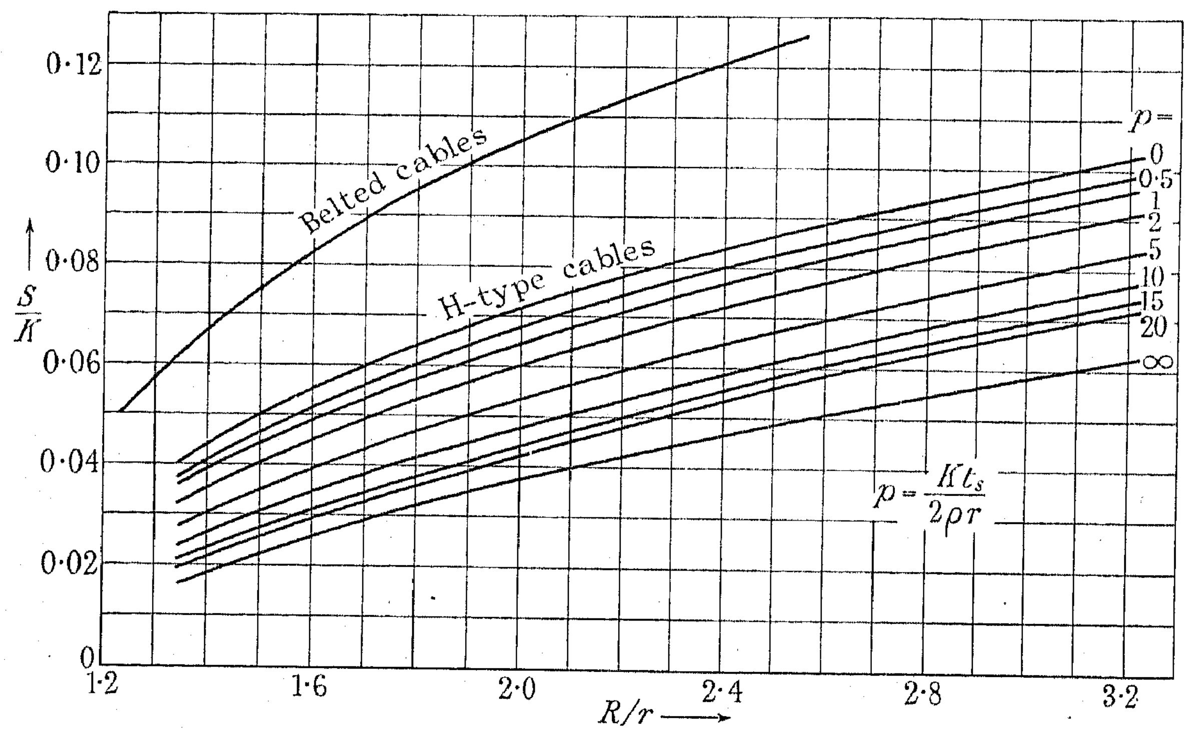


FIG. A.—Thermal resistances of circular H-type and belted cables.

S = Thermal resistance of dielectric in thermal ohms per cm.
K = Thermal resistivity of dielectric (usually assumed to be 550).
t_s = Thickness of screen.
R = Radius of screen, or radius over core papers.
r = Radius of conductor.
ρ = Thermal resistivity of screen material = 0·27° C./watt for copper; 0·5° C./watt for aluminium; 0·92° C./watt for brass; and 2·9° C./watt for lead.

The effect of the thickness of the foil on the thermal resistance might possibly be deduced from Fig. 4 of the paper, but it is not clear what exactly is meant by the "screen-element thermal resistance" or how this value is deduced from the thermal resistivity of the metal foil. Recourse can, however, be made to the elegant method first developed by Dr. K. Konstantinowsky and L. Tschiassny,† the tests being later recapitulated by Hofman, using more accurate apparatus, and

* Paper by Mr. H. WADDICOR (see page 195).

† K. KONSTANTINOWSKY and L. TSCHIASSNY: "A New Type of Cable," Report of the International E.H.T. Conference, 1927, vol. 1, p. 796.

the results published in a paper by L. Tschiassny.* As their method satisfies two essential desiderata from the cable designer's point of view, i.e. generality of application and ease of manipulation, I think that their work deserves better recognition in this country. I have therefore obtained permission from Dr. Konstantinowsky to reproduce in Fig. A curves giving the thermal resistance of H-type cables. From these curves it will be noted that there are two limiting conditions, corresponding to the cases in which the screen conductance is zero and infinite. In both of these cases alternative formulæ are available, and the agreement is excellent. Simons's formula for H cables gives results in close accord within the range for which it is valid, and otherwise the results are in agreement with those of the author.

TABLE A.

	20 kV		33 kV	
Dimensions, in inches	H	S.L.	H	S.L.
Radius of 0·25 sq. in. strand	0·3255	0·3255	0·3255	0·3255
Dielectric thickness . .	0·23	0·23	0·325	0·325
Inner radius of screen	0·556	0·556	0·651	0·651
External radius of lead or radius of lay-up	1·37	1·42	1·58	1·65
External radius of outer covering . .	1·67	1·72	1·88	1·95

TABLE B.

Current-Carrying Capacity for a Maximum Conductor Temperature of 65° C.

Cable	H Type					S.L. type
	Aluminium foil of thickness			0·003 in. brass tape	0·003 in. copper tape	
	0·0005 in.	0·001 in.	0·002 in.			
	amps.	amps.	amps.	amps.	amps.	amps.
20 kV	335	338	342	341	349	343
33 kV	331	334	338	337	347	342

It is very useful now to have means for dealing with the S.L.-type cable, and in the convenient form given in Fig. 10 of the paper. Although I hold no particular brief for this type of cable, I think that the second paragraph on page 203 is very misleading. The author has unjustly compared the thermal resistance of an armoured S.L. cable with that of an unarmoured H cable. If the latter is armoured and has a bedding thickness of 0·15 in. this paragraph should read as follows:—

" The value of 39·5 thermal ohms for the S.L.-type cable should be compared with the corresponding values of 36·4 for a screened cable with 3-mil copper-tape screens, 42·4 for a cable with 1·5-mil aluminium-foil screens, and 50·8 for an unscreened cable."

The bedding thickness of 0·15 in. assumed by the author in this example is larger than would be ordinarily encountered in practice. A better average would be under 0·1 in., and this would reflect more favourably on the S.L. cable.

As I think cable users would be interested in the relative current-carrying capacity for a given temperature-rise of some standard types of cable laid under practical conditions I have worked out the values given in Tables A, B, and C.

Designs are limited to 20-kV and 33-kV tape-armoured cables of conductor sections 0·25 sq. in., and the cables are supposed to be laid at a depth of 3 ft.

The current-carrying capacities of the above cables to the nearest ampere are set out in Table B.

Expressing the current ratings as percentages of the rating of an H cable with copper foil, Table C is obtained.

TABLE C.

Relative Percentage Rating.

Cable	H type					S.L. type
	Aluminium foil of thickness			0·003 in. brass tape	0·003 in. copper tape	
	0·0005 in.	0·001 in.	0·002 in.			
	per cent	per cent	per cent	per cent	per cent	per cent
20 kV	96·1	97·0	97·9	97·7	100	98·4
33 kV	95·8	96·7	97·8	97·6	100	99·0

These figures will better enable both cable designers and users to appreciate the effect of the type of foil or tape used as the equipotential screen for H-type cables, on the current-carrying capacity for a given temperature-rise. There are, of course, other factors both economic and technical which influence the design of foil, but these can be left safely to the manufacturers. In certain cases the practice of applying two metalized paper foils, face to face, with 50 per cent overlap, has been adopted, which doubles the effective thickness. Also it is generally recognized that an H-type cable will work satisfactorily at a higher maximum temperature than a similar S.L. cable.

Mr. H. Waddicor (*in reply*): Replying to Mr. Webb, formula (1) is the one derived by Simons for the condition of tangency between the screens and sheath, which is the condition assumed in the paper. The modified formula quoted by Mr. Webb assumes, on the other hand, that there is a definite arc of contact between the two electrodes. On sawing through a screened cable this feature is often exhibited, but the length of contact path is a very variable quantity, and furthermore, owing to core and sheath expansion, it is extremely probable that

* L. TSCHIASSNY: "The Heat Dissipation Conditions in Three-Core Cables of Non-Circular Cross-Section," *Archiv für Elektrotechnik*, 1931, vol. 25, p. 450.

conditions are quite different at times of maximum load. Hence, in my opinion, it is better to err if anything on the safe side by assuming line contact only between screens and sheath.

With regard to the aluminium foil used for screening, a thickness of 1·5 mils has been extensively employed in the past, and a tolerance of $\pm$ 10 per cent would be ample to provide for manufacturing variations. Changes of this magnitude would, of course, have no significant effect on the thermal resistance.

In cases where foil thicknesses greater or less than 1·5 mils are adopted, or in fact for any metallic screens coming within the range of the experiments, the basic diagram given in Fig. 4 can be used. This diagram has been completed by interpolating additional curves by the method suggested in the paper, and is reproduced in Fig. B. In order to make things perfectly clear, Fig. B will be used to obtain the thermal resistance of a 33 000-volt, 3-core, 0·25-sq. in. cable having screens of 1-mil aluminium foil ($\rho = 0 \cdot 48$). In this case $t_c = 0 \cdot 325$ in. and $d = 0 \cdot 651$ in., so that $t_c/d = 0 \cdot 5$. The only other calculation is that of the screen element thermal resistance, which is the thermal resistance in a circumferential direction of one of the 24 elements into which the complete screen has been assumed to be divided. It is, therefore, given by

$$s = \pi(d + 2t_c)0 \cdot 48/24t_s$$
$$= \pi \times 1 \cdot 301 \times 0 \cdot 48 \times 1\,000/24$$
$$= 81 \cdot 6 \text{ thermal ohms per cm length of cable.}$$

Entering the diagram with this value, and following the dotted lines, the thermal resistance of the cable is found to be 34·6 thermal ohms. Cables having a dielectric of non-standard thermal resistivity K' can be catered for by entering the diagram with a screen element thermal-resistance value of $550s/K'$, and multiplying the corresponding reading on the vertical scale by $K'/550$. For example, if the dielectric thermal resistivity K' in the above example was 700, the diagram would be entered with the value $81 \cdot 6 \times 550/700 = 64 \cdot 1$, as shown by the chain-dotted lines, and the thermal resistance of the cable would be $33 \cdot 4 \times 700/550 = 42 \cdot 5$ thermal ohms.

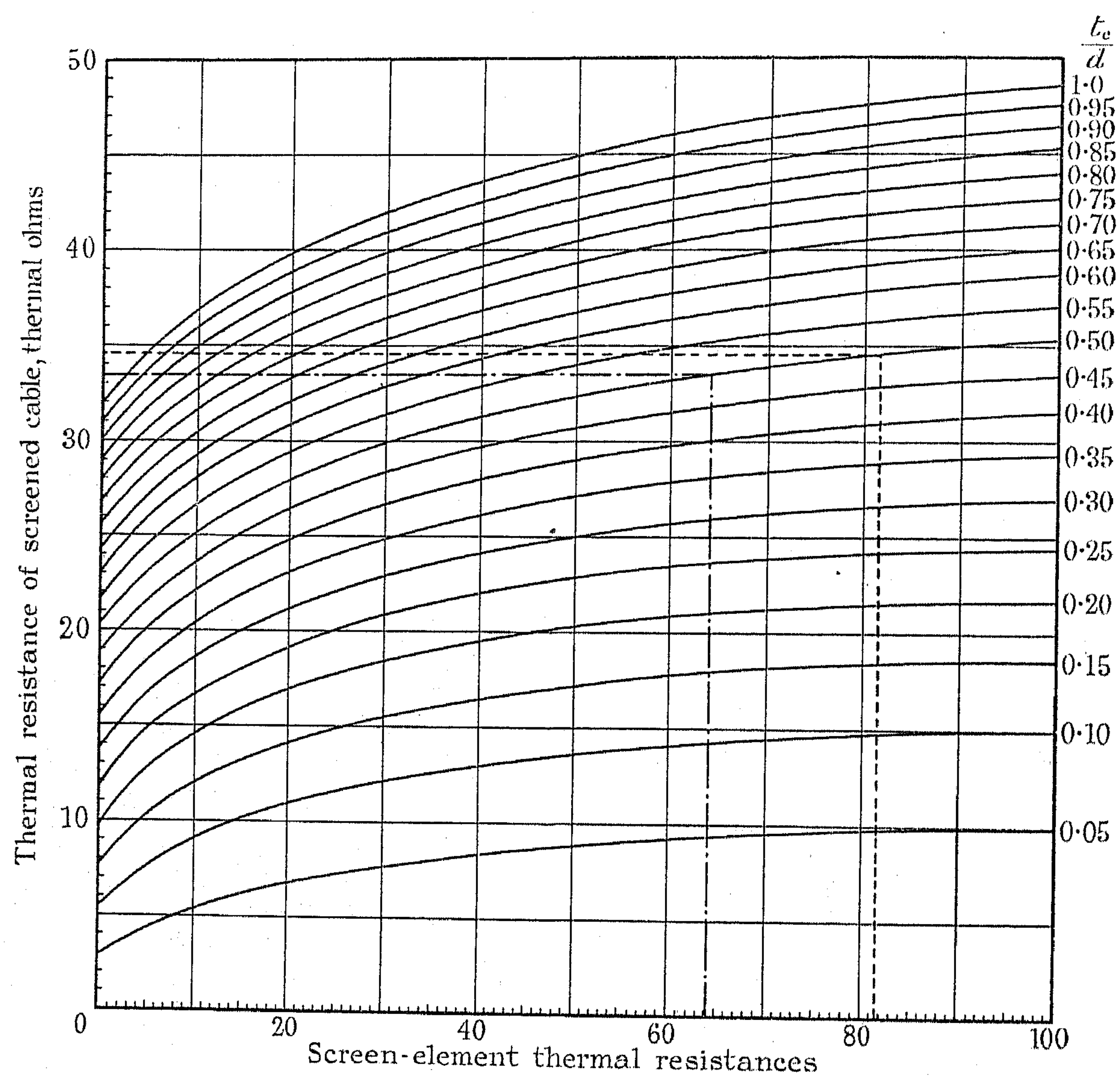


FIG. B.—Thermal resistance of 3-core screened cables ($K = 550$).

Drs. Konstantinowsky and Tschiassny should be given full credit for their pioneer work on the problem, using the electrolytic method, and at first sight this method appears to be more attractive than my own, as it does not necessitate any artificially assumed flow lines in the filler space. Nevertheless, this slight gain in theoretical accuracy may be offset by the increased difficulty of measurement inherent in any method using electrolyte, due to surface-contact effects at the electrodes, and changes of temperature or concentration. Fortunately, the two upper curves obtained by the electrolytic method, which are applicable to unscreened cables, can be checked by Simons's geometric-factor curves, the latter being based primarily on exact formulæ. It seems more than mere coincidence, therefore, that when this comparison is made the results obtained by the electrolytic method are found

to be from 2 to 4 per cent low, which is the same degree and mode of divergence also found between the curves applicable to screened cables and my own results.

As regards the comparison between the thermal characteristics of screened and S.L.-type cables, I cannot agree that any injustice has been done to the latter type of cable. The diameter and make-up of the particular cables compared were those recommended by a firm supplying both types, and the final protection for cables to be buried direct in the ground would be:—

(1) A 0·15-in. serving of hessian tapes over the armouring of the S.L.-type cable.

(2) A 0·128-in. steel armour and 0·15-in. serving of hessian tapes over the lead sheath in the case of the screened cable.

The thermal resistance of the same thickness of serving would thus have to be taken into account in each case when comparing the complete cable assembly, and the relative positions of the two cables would be unaffected.

Owing to the shape of the curve showing the thermal resistance of the material between sheaths and armouring of an S.L.-type cable (Fig. 10), a reduction in thickness of this material from 0·15 in. to 0·1 in. would have comparatively small influence on the thermal resistance of the cable. The improvement due to this cause would certainly not affect the general conclusions reached with regard to the relative thermal characteristics of screened and S.L.-type cables.

In considering the design of screens for cables, a certain minimum thickness of metal tape or foil is necessary, from considerations both of electrical conductivity and of mechanical strength. Above this thickness the question arises as to whether it would be better from the point of view of current-carrying capacity to increase the thickness of the screen or to spend the money on increasing the size of the conductor. In this connection it is very interesting to note that the economic thickness of aluminium foil is smaller than that of copper tape; and not only so, but that the actual dimensions of foil and tape employed in practical cables at the present day are, in fact, approximately those which would be dictated by purely economic considerations.

CARRIER-CURRENT TELEPHONY.*

By D. R. TURNER, B.Eng., Graduate.

(ABSTRACT *of a Paper read before the* SOUTH MIDLAND STUDENTS' SECTION, 18*th December*, 1933.)

Because the average telephone line will transmit without severe loss frequencies up to 30 or 40 kilocycles per sec., such a line is not being utilized to its full capacity when being employed solely for ordinary or "physical" speech, for which only a band of frequencies from 300 to 2 500 cycles per sec. is required. The possibility of utilizing the higher range of frequencies, in addition to the physical band, thus increasing the number of conversation channels per pair of wires, was seen by Huntin and Leblanc as early as 1892, but until the development of the thermionic valve and the electrical filter no results of practical importance were achieved, the first commercial effort being made in 1914 by the Bell Telephone Co. of America.

The removal of the voice-frequency band to a point higher up the spectrum is known as modulation, the form almost invariably used being amplitude modulation, in which method the amplitude of a wave of high frequency, known as a carrier wave, is made to vary in accordance with the voice currents. A mathematical analysis of the resulting wave shows it to consist fundamentally of three constituent waves of frequency $f_c + f_v$, f_c, and $f_c - f_v$, where f_c and f_v are the frequencies of the carrier-wave and voice currents respectively. Actually f_v stands for the whole voice frequency band, the term $f_c + f_v$ representing a band of frequencies known as the upper side-band, and the term $f_c - f_v$ a band of the same frequency width known as the lower side-band.

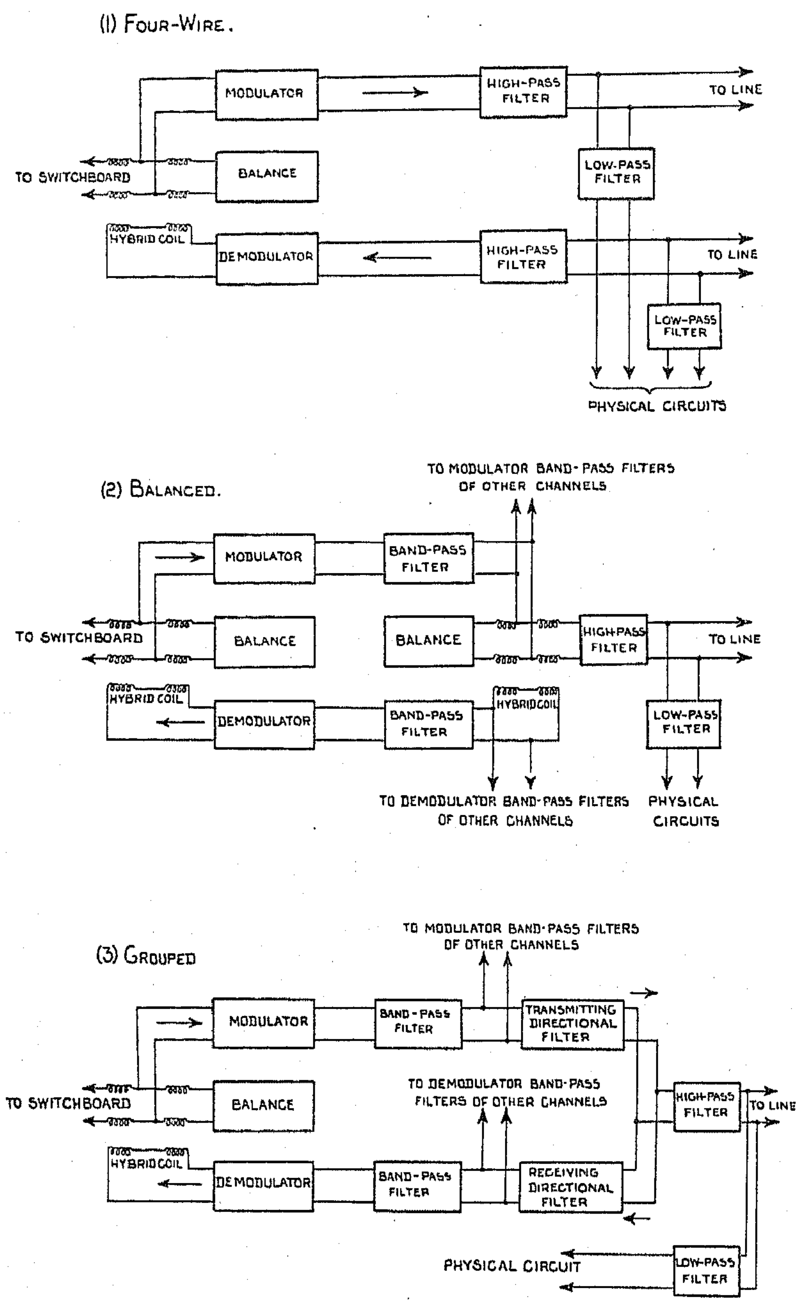
For demodulation all that is required to obtain the original voice-frequency currents is the carrier wave and one side-band, but it is not necessary to transmit the carrier wave over the line, it being sufficient to introduce into the demodulator a wave of this frequency from a local oscillator at the receiving terminal. Thus from the transmission point of view carrier-current telephone systems may be divided into three groups, namely: (1) Systems in which the carrier wave and the two side-bands are transmitted. (2) Single side-band systems in which one side-band is suppressed by filters, the carrier wave and the other side-band being passed to line. (3) Single side-band suppressed-carrier systems in which only one side-band is transmitted, the carrier wave being either balanced out in the output transformer of a push-pull modulator or suppressed by means of filters.

With very few exceptions the modulation is carried out by means of thermionic valves, the most popular

* A Students' Premium was awarded by the Council for this paper, and it is the practice of the Council in such cases to publish the paper, in full or in abstract, in the *Journal*.

methods being (1) anode-choke, (2) grid modulation, and (3) Carson's balanced modulation, which is a development of grid modulation utilizing two valves in a push-pull circuit in order to balance out the carrier wave.

Demodulation, by which the speech band is restored to its original position on the spectrum, may be regarded as modulation of the carrier wave by the side-band or



Methods of obtaining both-way communication.

side-bands, the original voice frequencies being among the resulting waves. Usually thermionic valves are employed for demodulation, although the crystal and the metal rectifier find frequent use in this capacity.

By suitable choice of carrier frequencies several "carrier" conversations can be superimposed over a telephone line in addition to the ordinary "physical" speech band, the actual number depending on the characteristics of the line and on the type of apparatus employed. In the terminal apparatus the currents corresponding to each channel are kept in their respective paths by means of filters.

Both-way communication is obtained by means of filters and hybrid coils, these latter being special transformers for connecting together 4-wire and 2-wire telephone circuits. The three usual methods of obtaining both-way communication, shown in the diagram, are as follows: (1) A 4-wire circuit is used, transmission being achieved over one pair and reception over the other. The connection to the exchange line is carried out by means of a hybrid coil on the voice-frequency side of the carrier apparatus. (2) A balanced system using a 2-wire circuit, the currents from the modulator side of the terminal and those going to the demodulator side being passed to and from the line by means of a hybrid coil at each terminal. The modulator and demodulator circuits are connected to the switchboard by another hybrid coil. The carrier waves for both directions of transmission can have the same frequency. (3) A grouped frequency system in which the carrier-wave frequency is different for either direction of transmission. Here the carrier channels are directed into their respective paths at the terminal and repeater stations by means of filters. Connection to the exchange lines is again made by means of hybrid coils.

The balanced system is most economical as regards frequency space, but, owing to the extreme difficulty in accurately balancing the line at all frequencies, it is rarely used except on cable circuits where the impedance/frequency curve is very smooth and changes of line loss due to varying weather conditions are not experienced. The grouped frequency system is extensively used for aerial lines, particularly in the case of single side-band transmission.

Thermionic valves are also used in order to amplify either the modulated wave or the speech currents, that is, as high-frequency and low-frequency amplifiers. In the case of high-frequency amplifiers, owing to the relatively low frequencies used, it is usual to utilize iron-core transformers and chokes. Dust cores are used where cross modulation between the various channels might result, and stalloy where this likelihood is absent.

At the high frequencies used in carrier telephony the characteristics of the lines become of great importance. Any irregularities such as change of impedance, due to cable sections or faults, cause reflection losses owing to part of the power being reflected back to the sending end. In the case of cable sections this loss can be lessened, either by matching the impedance of the cable to that of the aerial by means of transformers at the junction, or by loading the cable so as to increase its impedance to that of the aerial.

Cross-talk is more pronounced at these frequencies, and great care has to be taken in planning a carrier installation in order to ensure that interference from parallel systems is not experienced.

INSTITUTION NOTES.

Silver Jubilee of H.M. The King.

Authority has been given by the Council for the signing and sealing of a Joint Congratulatory Address from the engineering institutions to His Majesty The King, who is the Patron of the Institution, on the occasion of the Silver Jubilee.

Annual Conversazione.

The Annual Conversazione of the Institution will be held at the Natural History Museum, South Kensington, S.W., on Thursday, 20th June, 1935. Particulars will be circulated later.

Summer Meeting, 1935.

Arrangements are being made for a Summer Meeting to be held in Belgium, probably from the 8th to the 14th September, 1935.

The programme will include excursions and visits to works, and amongst the towns which are under consideration with a view to inclusion in the itinerary are Brussels (which will probably be the headquarters town, and where the Exhibition will still be in progress), Antwerp, Charleroi, Dinant, Langebrugge, Liège, Tirlemont, and also Ypres and other places connected with the battlefields of the Great War.

Full particulars will be circulated at an early date.

Transmission Section.

The Committee of the Transmission Section are desirous of making the Section's proceedings cover not only British but also overseas transmission and distribution problems and practice. They would therefore be glad to receive from overseas members, for consideration, papers and short communications likely to be of interest.

Elections and Transfers.

At the Ordinary Meeting of the Institution held on the 14th March, 1935, the following elections and transfers were effected:—

ELECTIONS.

Member.

Williamson, George William.

Associate Members.

Allen, William Shepherd, Flight-Lieut., R.A.F.
Barbour, Ralph Henry, M.A.
Bird, Neilson Mysore.
Bishop, John Montague, B.E.
Connell, Arthur Grevatt.
Cooper, Herbert John.
Das, Josiah Prema, B.A., M.Sc.
Dutton, Cyril Norman O.
England, William Lishman, M.Eng.
Holmes, Charles Ellwood.
Jeans, Archibald Edward.
Laurie, Kenneth Somerville, M.A.
Loehnis, Clive.
Lyall, David Wylie, B.Sc. (Eng.).
McDermott, Bernard Murray.
Nagle, Ronald Francis, M.Eng.
Petrie, William.
Potts, Edward.
Puritz, Mario E.
Scarborough, Walter Howard.
Singh, Har Chand, M.Sc., Ph.D.

Associate Members—continued.

Starr, Arthur Tisso, M.A., B.Sc., Ph.D.
Watkins, Joseph Henry.
Wood, George.
Wostear, Percy Leonard.

Associates.

Anderson, Joseph.
Austin, Arthur Richard.
Gray, Reginald Arthur G.
Hayden, William Benjamin.
James, Ivor Robert.
Moore, Sydney William.
Singh, Kirpal, B.Sc.(Eng.).
Sions, Morris Ernest, B.Sc.
Warren, Herbert.

Graduates.

Batten, Frederick John H.
Beech, Frank.
Berry, Thomas James.
Bradley, John Fox.
Carr, Gerald Richard.
Chorlton, Alan, B.Sc.Tech.
Clegg, Frank.
Coats, William Herbert, B.Sc.
Corn, William Norman.
Cox, Sydney.
Crawford, Alfred Thomas, B.Sc.
Dabin, Alfred William.
Dick, Robert Gillon.
Donnelly, Patrick Joseph.
Dyson-Laurie, Waulter de Molesworth, M.A.
ffoulkes, Arthur Kingsley F., B.Sc.
Foden, Harry.
Foster, George David.
Fuller, Philip William.
Gardner, Charles Everson, B.Sc., B.E.(Elect.).
Garner, Leonard Francis.
Gordon, Edward Alexander, B.Sc.
Gray, William.
Greenlees, Arthur Edward.
Guild, Joseph Buick.
Hand, Eric Joseph.
Hanna, Matthew.
Hayward, John Ralph G.
Higham, Sydney.
Hobbs, Albert Roy, B.Sc.
Hodges, Lawrence Wilfred.
Holt, John William, B.Sc.
Jewsbury, Eric.
Joyce, Richard Charles W.
Judd, Harry Edward.
Kater, Gregory Blaxland, B.A.
Lawson, Clement Stephenson.
Lowe, Bernard.
Martin, Clifford Trevethan, B.Sc.
Mason, Courtenay Thomas.
Meickle, Joseph Churchill.
Mew, Reginald John, B.Sc.
Mitchell, Jack Horrell, B.Sc.(Eng.).
Myers, David Milton, B.Sc., B.E.
Noblett, Richard.
Parker, George.
Peacock, James Benzie, B.Sc.(Eng.).
Possnett, Arthur Frederick J.
Priday, Percival.
Redpath, Francis Reginald.
Richardson, Alan Herbert D.
Rigby, Norman Hill.
Riley, Stephen.
Russell, Edward Storm.
Shaw, Norman Harry.
Slorick, William Alexander.
Slow, Ernest Clive, B.Sc. (Eng.).
Smith, Harry.
Stansfield, Hector Bryan, B.Sc.
Stevens, Eric Freeman.
Styles, Gordon Edward.
Tanner, John Patrick.
Trummel, Eric.
Turner, Godfrey Lester, B.Sc.(Eng.).
Verity, Alfred Samuel.
Walker, Albert.
Wilson, William John.
Winskill, James Edward.
Wooler, Alfred Ernest.
Woolgar, Charles Ernest, B.A., B.Sc.

Students.

Annandale, James.
Ashby, Donald, B.Sc.
Barker, Charles Edward.
Bartlett, James George.
Bateson, Alan.
Bernacchi, Michael Louis.
Britton, Alfred William.
Broadley, Alfred.
Brown, Geoffrey William.
Brown, Ronald James.
Brown, Wendell Arthur.
Cash, William Francis.
Clee, Gethyn Lewis.
Craik, Kenneth David S.
Cunningham, Alex Ernest.
Dixon, William Alexander.
Dobson, Arnold Tidswell.
Douglas, John Bell.
Duncan, Stuart.
Earl, Vernon Gascoyne.
Edmonds, Eric Walter A.
Edmonds-Brown, Harold Edward.
Elliker, William Ralph.
Evans, Daniel Thomas.
Faircloth, John.
Gent, John Peter A.
Glover, John Hampton.
Godwin, Charles Harold.
Goodall, George Reuben.
Gregory, Leslie Howard J.
Gregory, Michael Craven.
Grugeon, Derek Granville.
Haines, James Stacey.
Harper, Maurice Ernest.
Harris, Albert Robert.
Harrod, Kenneth William G.
Harwood, Thomas Fairfax, B.A.
Hayward, Ronald Lionel.
Hedley, Oswald Chisholm.
Henderson, John.
Hill, Clifford Arthur R.
Horton, Ronald Clarence, B.A.
Houchin, David Arthur R.
How, Richard Clive.
Humphries, Selwyn James.
Jackman, Bernard George L.
Johnson, Maurice Peter.
Jones, Norman Wilfrid.
Joyner, Walter Stanley.
Kameen, Robert James.
Kenworthy, George Fredrick.
King, Geoffrey.
Kirk, Frank Henry.
Kirkland, Stanley.
Knapp, Archibald James.
Krishnaswamy, Vippodu, B.A., B.Sc.(Eng.).
Leigh, Edwin Stuart.
Lloyd-Jones, Arthur Edward.
Lord, Arthur Newnham.
Lovelace, Ralph Claud H.
Macfarlane, George Gray.
McKibbin, Edwin Lawson.
MacLean, Duncan MacDougall.
McOwen, Rowland William.
Manser, Robin.
Marshall, Maurice.
Matthews, William Laugher E.
Mears, George Arthur.
Mellanby, Harry.
Morgan, Edward Merlin.
Morgan, John Louis W.
Naaman, Khurshid.
Nanda, Manohar Lal.
Nicholas, John Harold.
Nicholas, Walter Archibald, B.Sc.
North, Frederick William.
Oxley, John Harrison.
Palmer, Ronald Richard.
Parr, Frank Douglas.
Partridge, George Harold.
Phillips, Clive Joseph.
Roberts, William Eric.
Roy, Tara Bilas.
Slater, Norman Charles.
Slatter, John Reginald.
Smith, Edward Turner.
Srivastava, Jagmohan Krishan.
Swinney, Edward.
Thomas, Gwilym Evan.
Thomas, Hubert Henry.
Todd, Ian Campbell.
Todd, Julian Kelsall.
Upperton, Maurice Prescott.
Walker, Ernest Harold.
Walker, Ronald Charles W.
Waloff, Dmitri.
Webb, Denis Chaundy.
Wilkins, Dennis Harold.
Wilson, Alastair Graeme.
Wright, Albert Douglas.
Young, Eric Deans.

TRANSFERS.

Associate Member to Member.

Batt, Frederick Horace.
Carnegie, Herbert Stirling.
Favell, Frederick.
Gyles, John Herman.
Highfield, Frank Wootton.
Kaempf, Emil.
Ketton, Harold Isaac.
Kinnear, Robert Inglis.
Pickles, John Sydney, B.Sc. (Tech.).
Smith, Charles William.
Stubbs, Albert, B.Sc.
Winstanley, Henry Murray.
Wright, John Edwin.

Associate to Associate Member.

Seaborne, William.

Graduate to Associate Member.

Berry, Herbert, B.Eng.
Brinkworth, Leofwin Lennox, B.Sc.
Chapman, Geoffrey Tancock
Clarke, Robert.
Dillamore, Alfred William A., B.Sc.
Felton, Alonzo, B.Sc.(Eng.)
Gould, Ephraim Frederick H., B.Sc.(Eng.).
Hart, Stanley Haines.
Henderson, Douglas Hedley P.
Jenvey, Frederick James, B.Sc.(Eng.).
Kay, Jack.
Kenyon, Alec Hindle.
Lee, Williamson.
Leigh, Harold, B.Sc.(Eng.).
Lewis, Norman William J., B.Sc.(Eng.).
Loveridge, Eric James.
McIlwrick, Gilbert Menzies, B.Sc.
Maw, Eric.
Nye, Edward Philip.
Rowson, Robert Bryan, B.Sc.
Smail, George Grey, B.Sc.
Storie, Robert Pow.
Thompson, Henry.
Weston, Gordon, B.Sc. (Eng.).
Whibley, Cyril George, B.E.

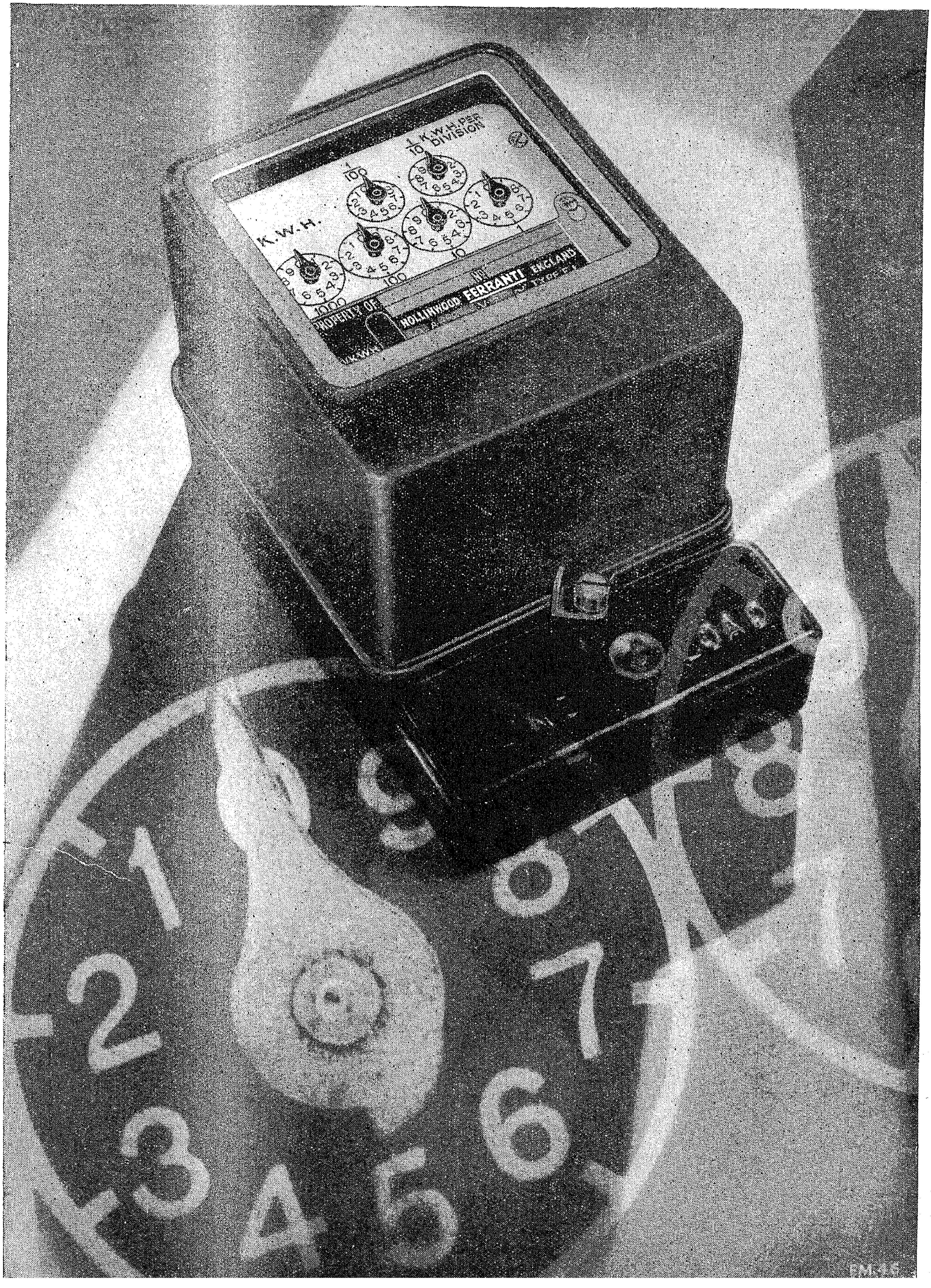
Student to Associate Member.

Baly, Wilfred Frank, B.Sc. (Eng.).
Ralph, Frank, B.Sc.

In addition, the following transfers have been effected by the Council:—

Student to Graduate.

Allen, Harold Justice.
Arnold, Arthur Laurence B.
Baker, George Albert.
Baker, Howard, B.Sc.(Eng.).
Bennett, David Paterson.
Bennett, William Moore.
Brecknock, Howard, B.Sc. (Eng.).
Buckley, Cornelius.
Burns, Ivan George.
Carpenter, Alan Bertram.
Copinger, Walter Patrick.
Fidlan, Frederick, B.Sc. (Eng.).
Fowlds, Ronald Humphrey.
Gibson, Arthur Charles.
Glover, Roy Phillips, B.Sc.
Guest, Brian Carwardine.
Gulati, Bhisham Ji, B.A., M.Sc.
Handyside, John Stewart.
Harper, William Eric, B.Sc. (Eng.).
Harris, Kenneth Glanfield.
Haslett, Kenneth.
Houghton, Leslie Wilfred.
Iyengar, Minasamudram Venkatachar A., M.Sc.
Laing, George Gilchrist.
Lewis, Kenneth.
Mallett, Leslie Henry.
Murty, Krishna Radha K.
Nair, N. A. Karunakaran, B.A.
Neill, Victor Alan.
Nield, Charles Francis.
Parry, Donald John C.
Preston, George Neil.
Samra, Farid Daoud, B.Sc.
Shuttleworth, Samuel Norman.
Sohoni, Krishna Vaman.
Spriddle, Francis John.
Tudhope, Graham Wainwright.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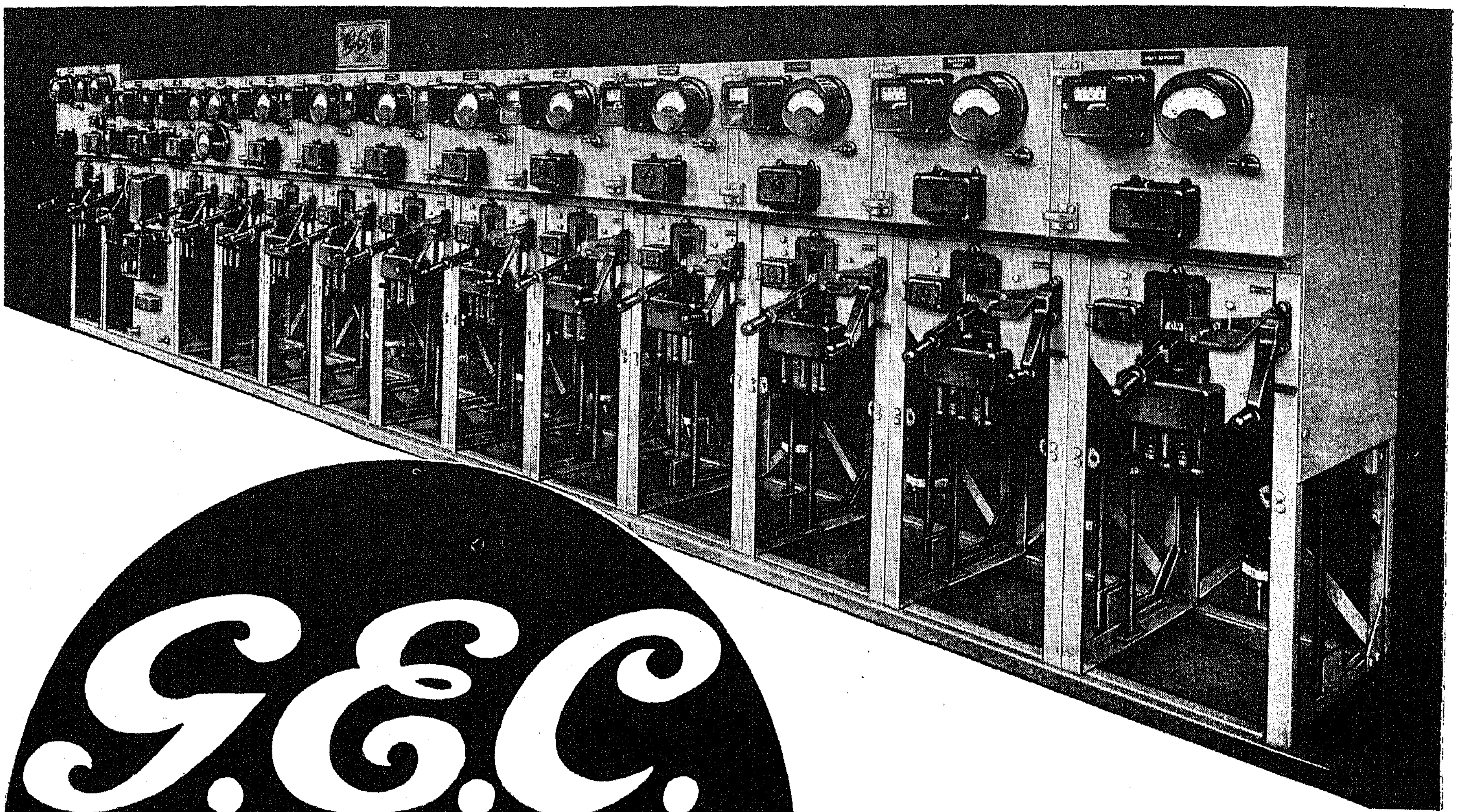

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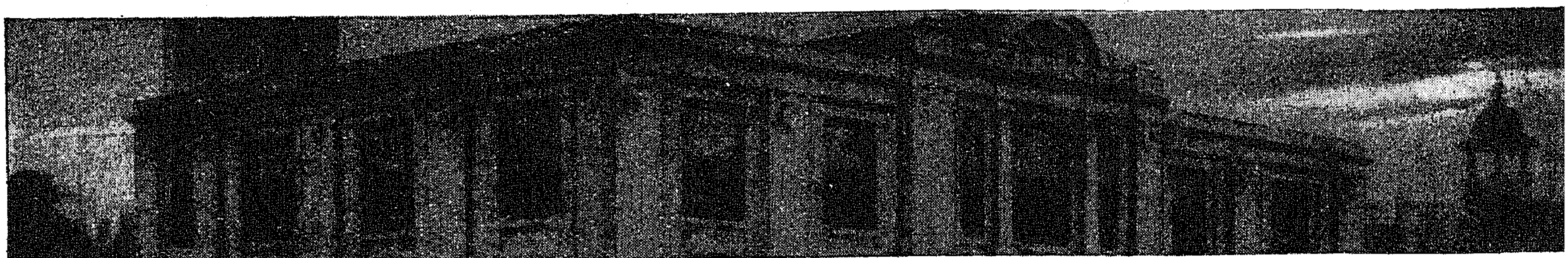

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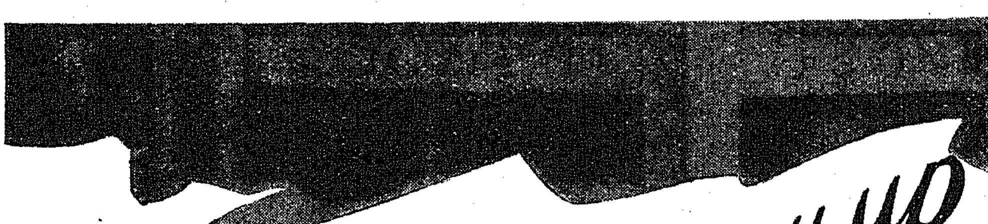

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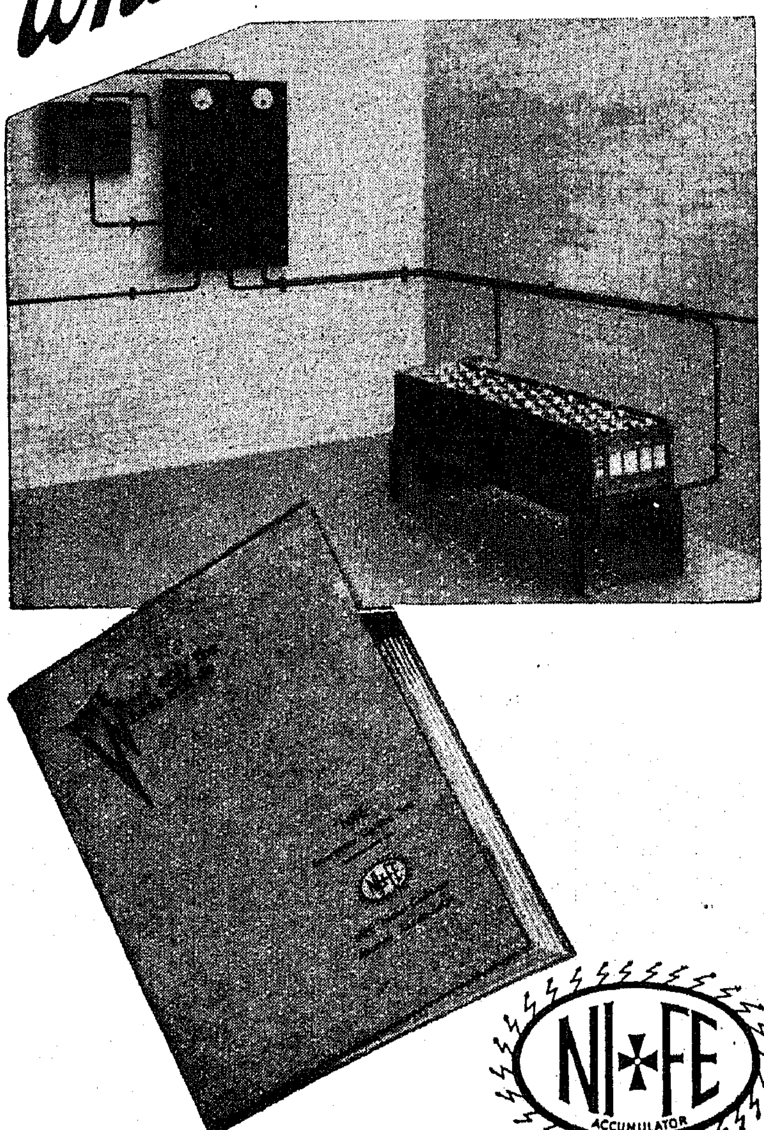

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Hon. Secretary.—A. G. Hiscock, 25, Burbidge Grove, Southsea, Hants.

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Chairman.—Prof. J. T. MacGregor-Morris.

TRANSMISSION SECTION.

Chairman.—R. Borlase Matthews.

WIRELESS SECTION.

Chairman.—S. R. Mullard, M.B.E.

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